Detectors for Synchrotron Radiation Experiments- Maintaining the Status Quo or an Opportunity for change.

SRI 2003

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Introduction to talk:- structure

- History
- Present

  (some examples)

- Possible Futures

  short term

  longer term

The History of detectors for SR science is one of under investment.

Funding usually goes in the following sequence:-

1. Source

2. Beamlines

3. Experiment

4. Detectors (maybe) (or maybe not)

Introduction- History

This contrasts with other areas of Science:-

HEP being the most noteworthy example

but Neutron Science also invest in detector systems as a key part of the whole drive to enable efficient use of the flux provided by the source.

We are only as strong as our weakest point !

Without co-ordinated investment, led by the science, SR will lose out long term.

Introduction - History

Note the emphasis on "science led".

Things that have gone wrong:-

There are many cupboards with detectors in which made it to the beamline too late (if ever!).
A fundamental flaw in what was proposed (Technical, Funding or Project Methodology)

Technology push is OK if it is linked with the true people who want to do science.

Because of inherent lack of funding and large opportunities some projects are overly ambitious or so wide in their constituents that they do not deliver specifics.

Where is the SR community at the present with detectors?

In the 1990’s at the very latest!

SRI 91 Prof. Mike Hart’s keynote speech pointed out the widening gap between source provision and detector capability.

Has the situation changed since then?

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Present Time

In a small number of cases yes!

In a number of cases some key progress has been made.

(but availability to the wider community?)

In a large number of cases no (or slow) progress because of lack of critical mass.

Or it has got worse?

Present Time

Successful conventional approaches to development:-

Incremental, longer term.

Usually drip feed of small amounts of funding over several projects.

Extension of science area slow and can lead to FBAD (funding body attention deficit).

Successful More Radical approaches to development:-

Step change development, short term.

Borrow what you need to prove things work, limit risk.

Then ask for real amounts of funding to complete, possibility of success binary. But usually gets attention.

Two examples

an incremental development which is not quite there yet

a rapid step-change development which is now available to the community.

These are C-TRAIN X-SPRESS

and XSTRIP

C-TRAIN X-SPRESS project

Canberra multielement 1988

prototype digital signal processor early1992

X-SPRESS system built and tested 1995

Ortec 30 element Ge plus X-SPRESS 1997

Ortec 9 element monolithic plus X-SPRESS 1998

other Ortec monolithics plus X-SPRESS 2002, 2003

X-SPRESS2 2004?

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C-Train X-SPRESS model

Science Need

Funding Tech. Dev.

Funding Science Dev. Commercial ops

Optimisation

Funding Tech. Dev. Commercial ops

Funding Science Dev.

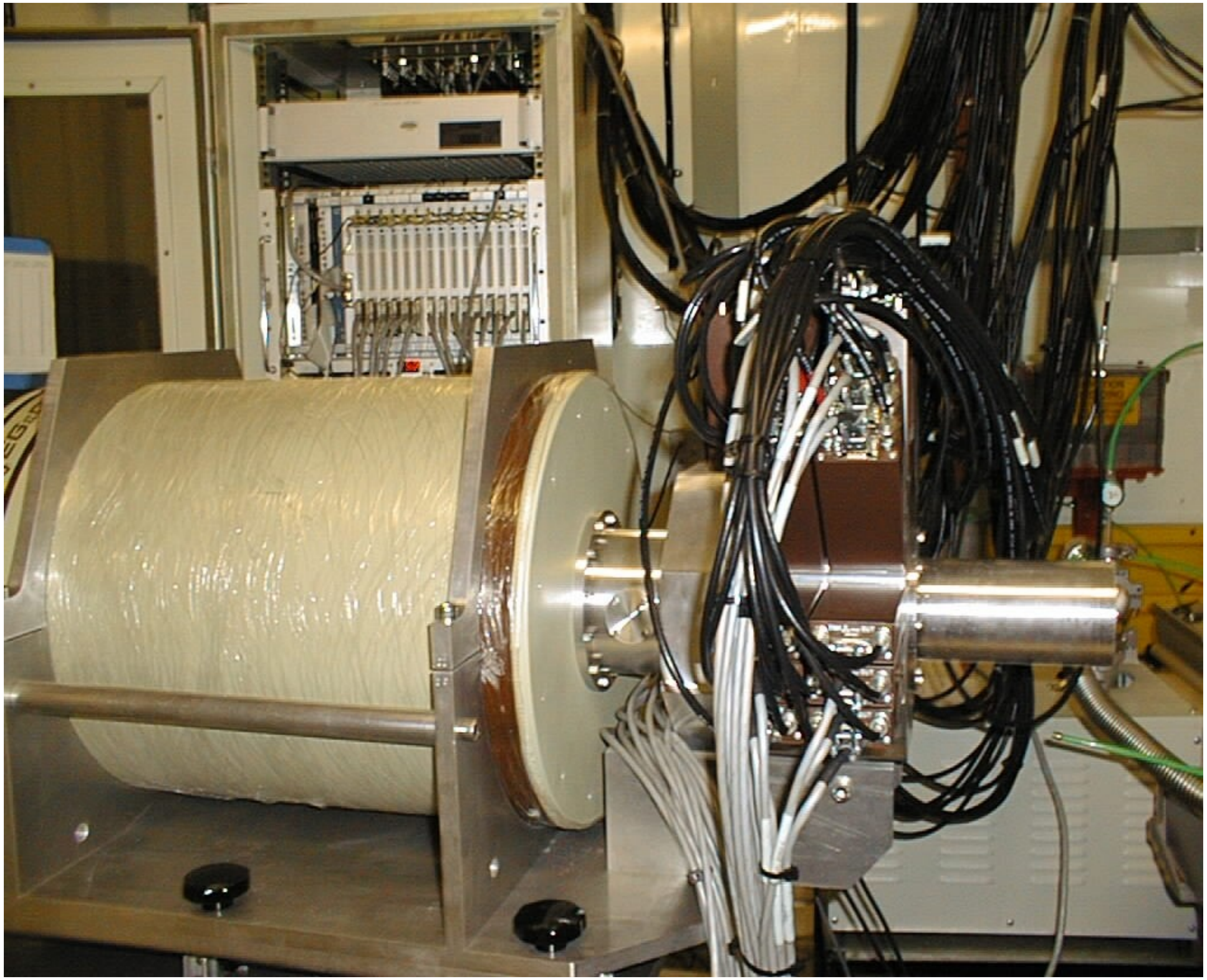
Optimisation

The aim of the C-TRAIN X-SPRESS programme:-

To develop an optimised fluorescence XAS system.

- **High throughput**
- **Flexible**
- **Compact**
- **Easy to use / low maintenance**

The first X-SPRESS SYSTEM with ORTEC 30 element in early 1997 SRS 16.5

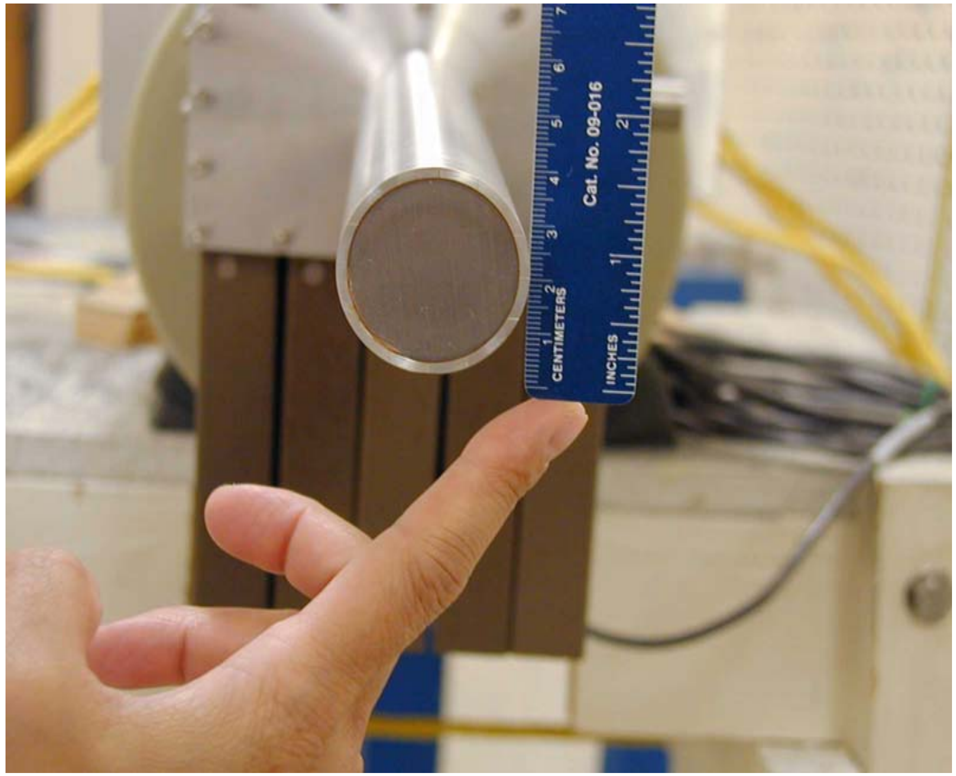


The 2nd System X-SPRESS based system C-TRAIN towards end 1998

CTRAIN

Compact Time Resolved -XAFS Array INnovation

C-TRAIN COMPACT FRONT END optimisation



Courtesy of Pat Sangsingkeow, Ortec

Overview of first results

The overall initial results achieved:-

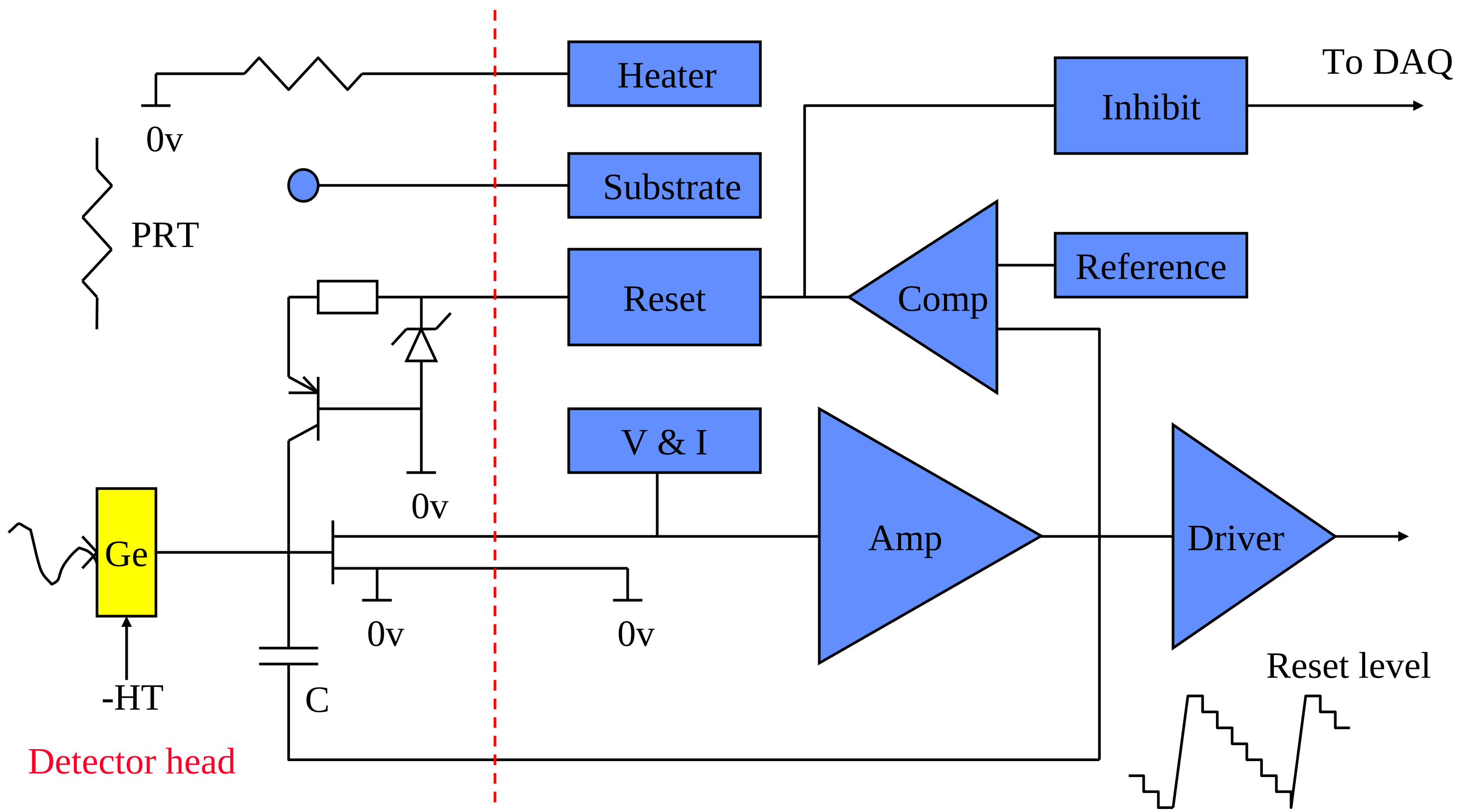
- **9 Element Germanium Crystal**

- **Maximum count rate is 550k CPS per channel**

This could be improved

- **Resolution is < 200 eV FWHM, typical 170eV FWHM @ 0.5 microseconds shaping equivalent.**

Front-end Preamplifier



Front-end design considerations

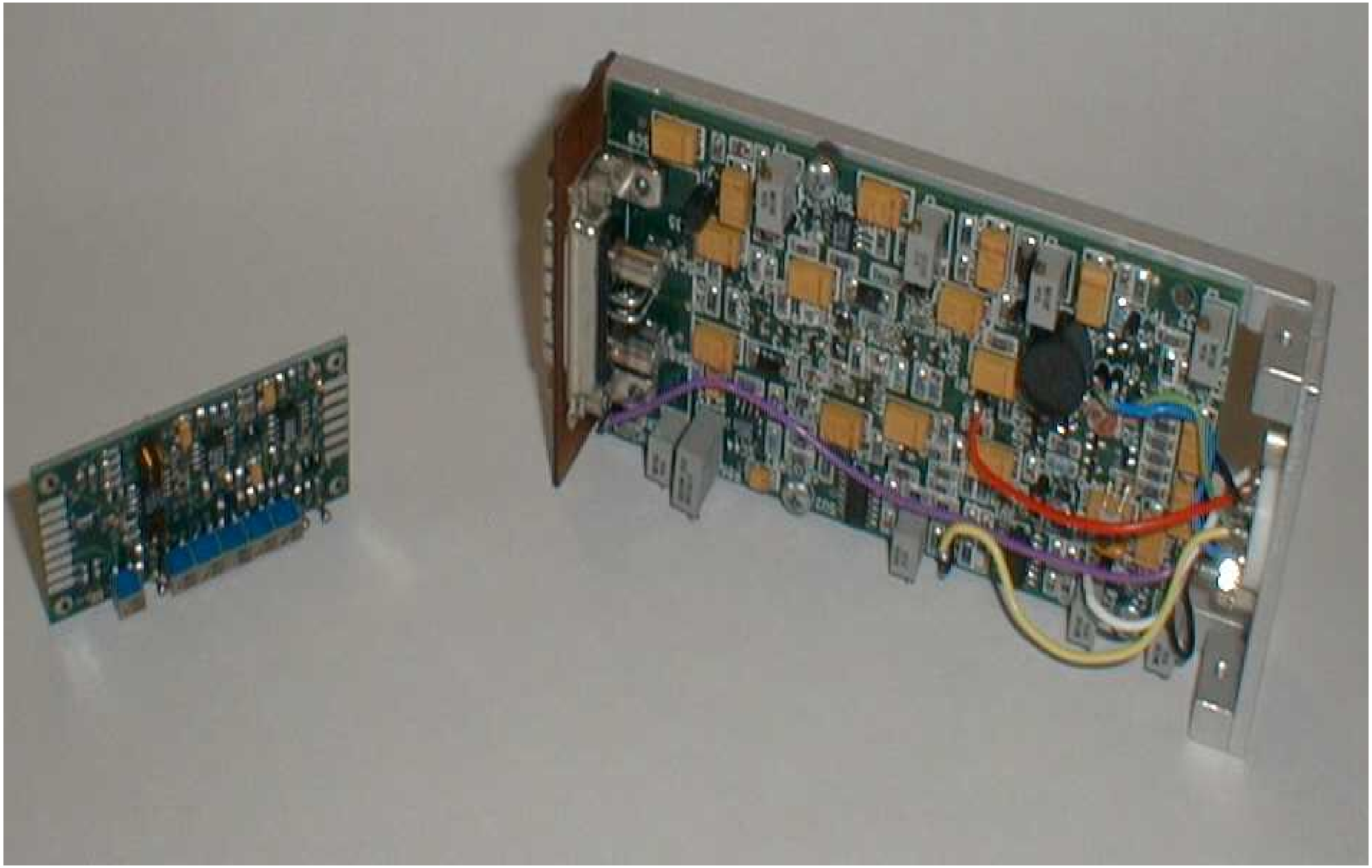
- **Improve Reset Time**

- **Interface with existing DAQ and cables**

- **Retain existing good resolution**

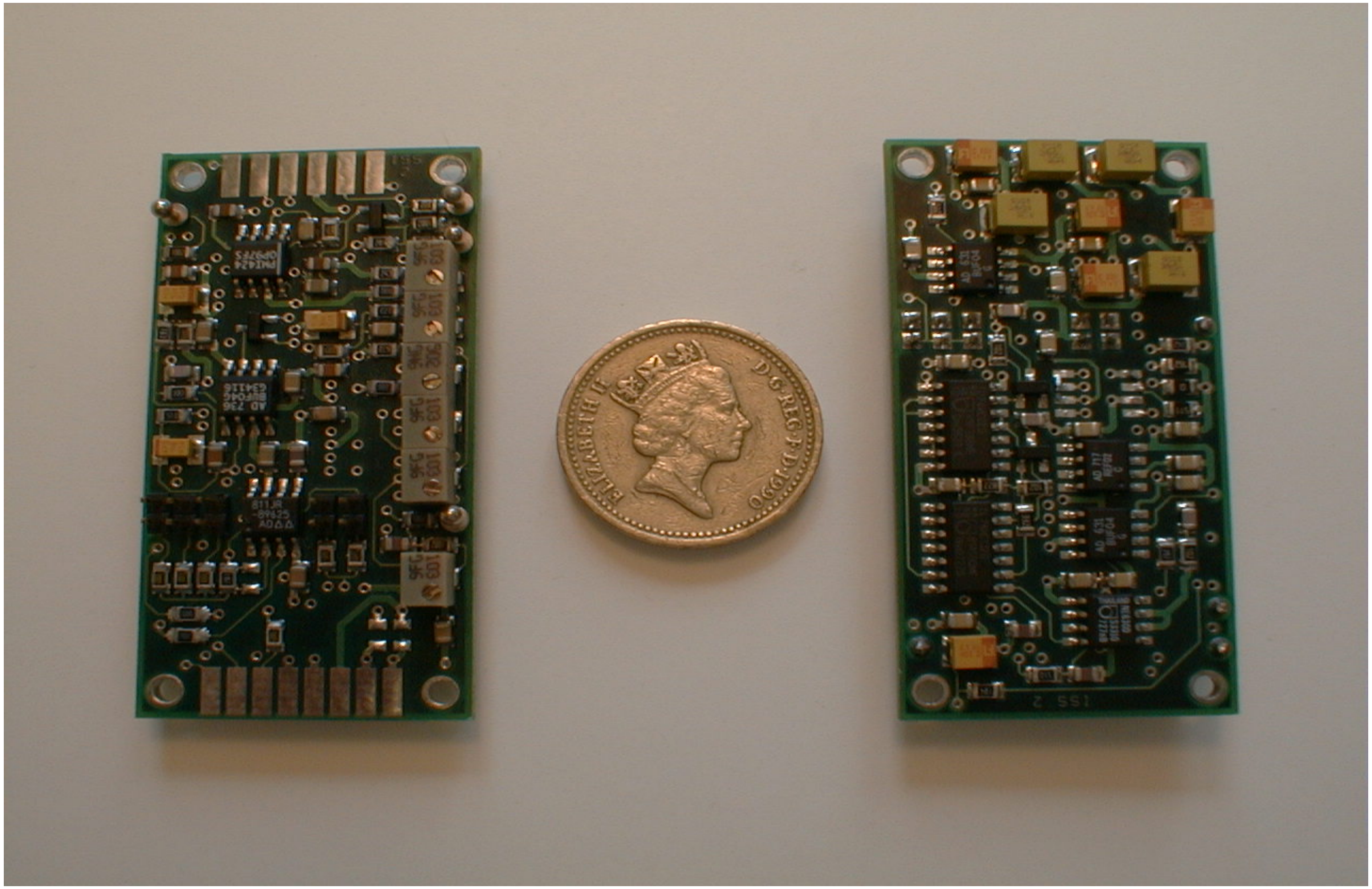
- **Improve count rate**

New Preamplifier compared with Previous preamplifier

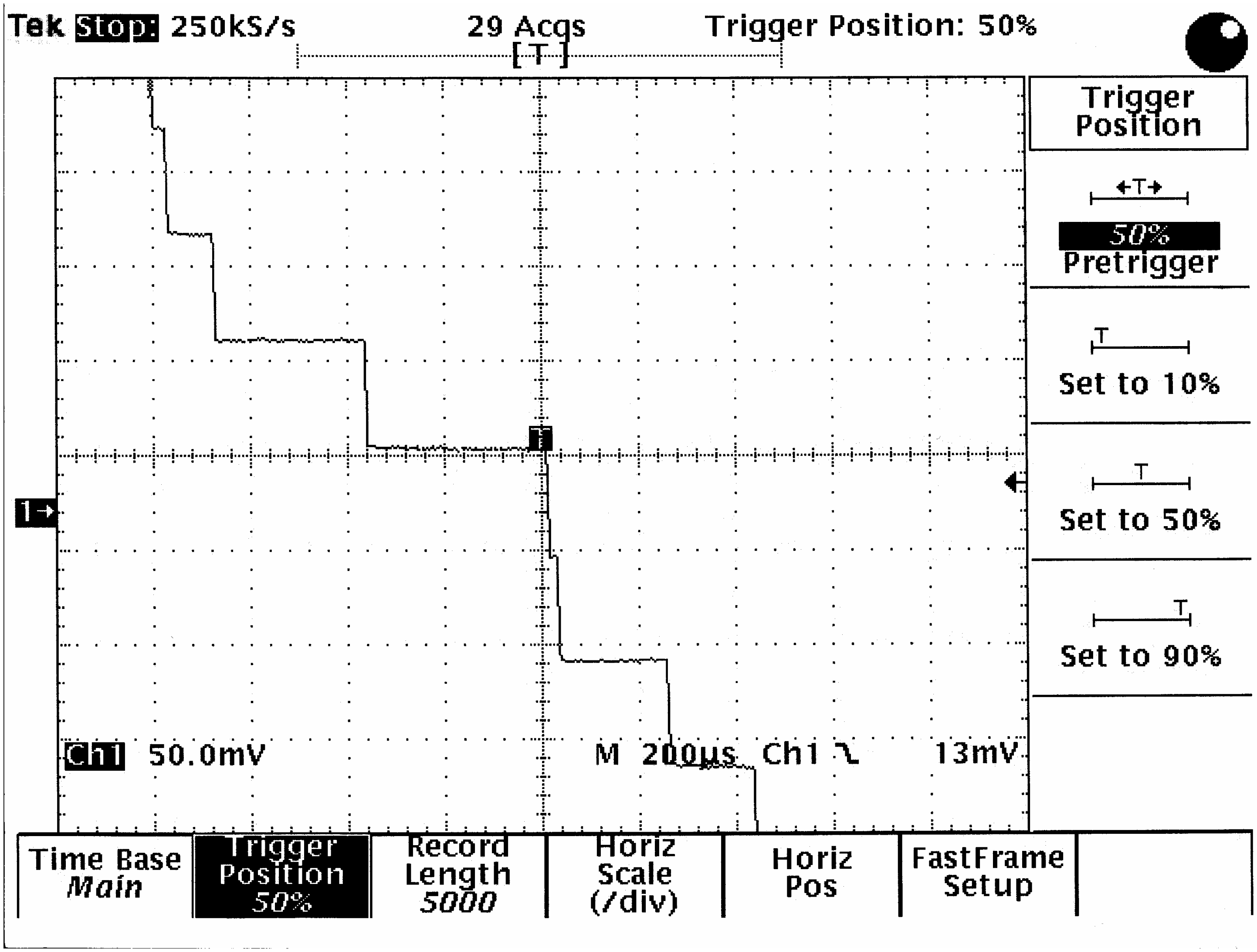


New Preamplifier

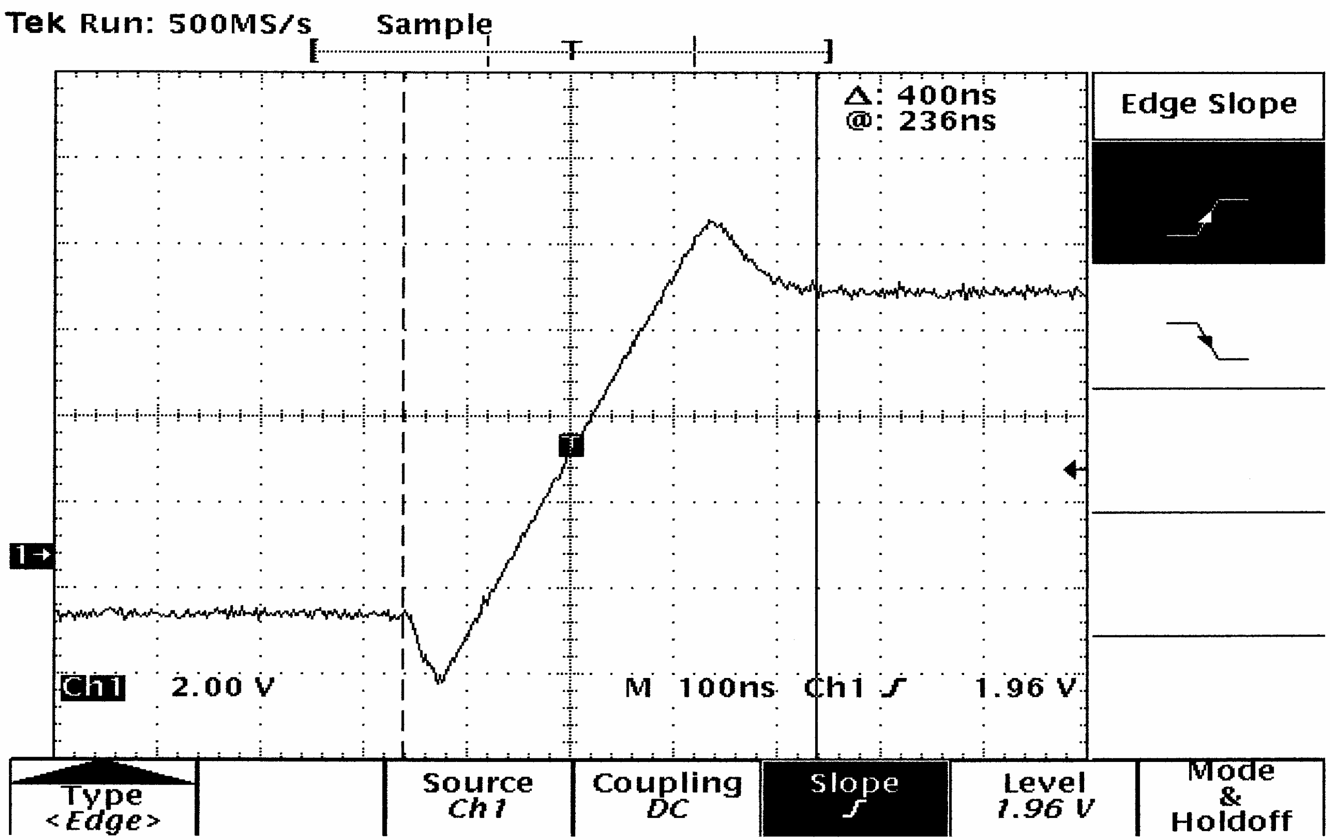
Analogue Side **Digital Side**



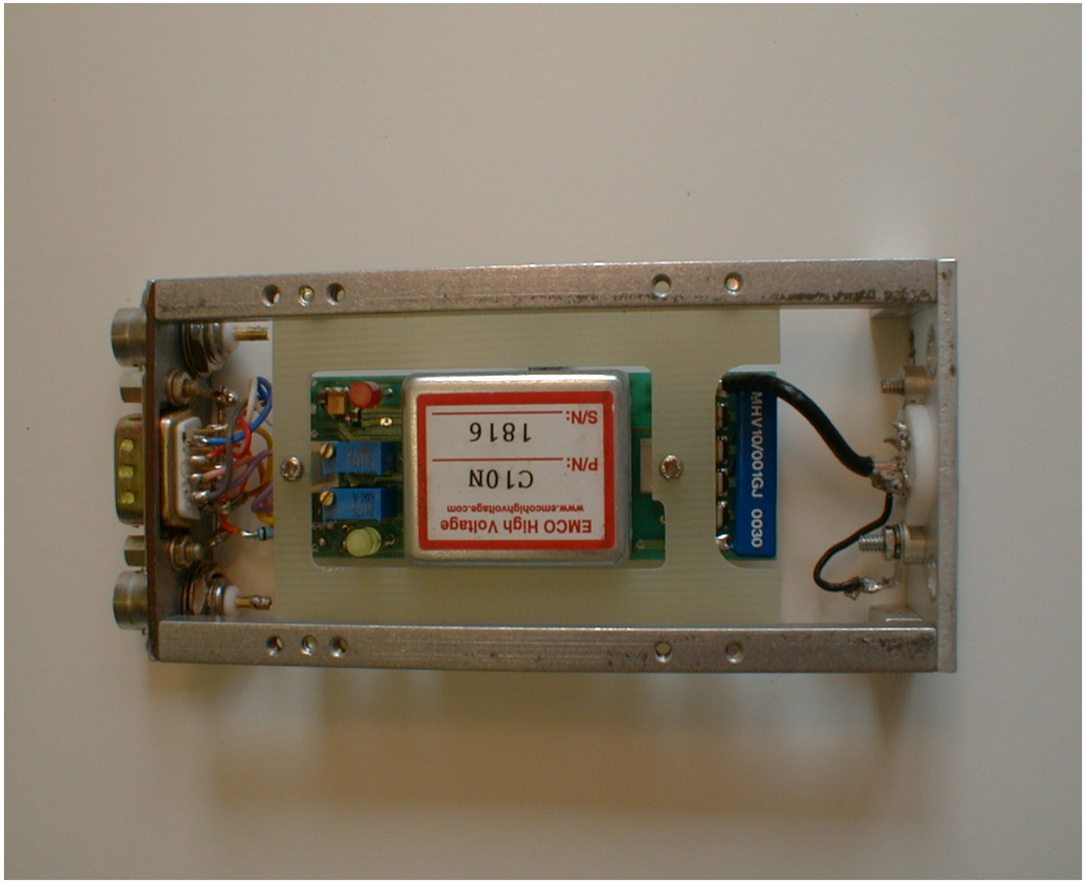
The Preamplifier Output



The C-TRAIN Preamplifier Reset



New Compact High Voltage Supply



The rest of the system

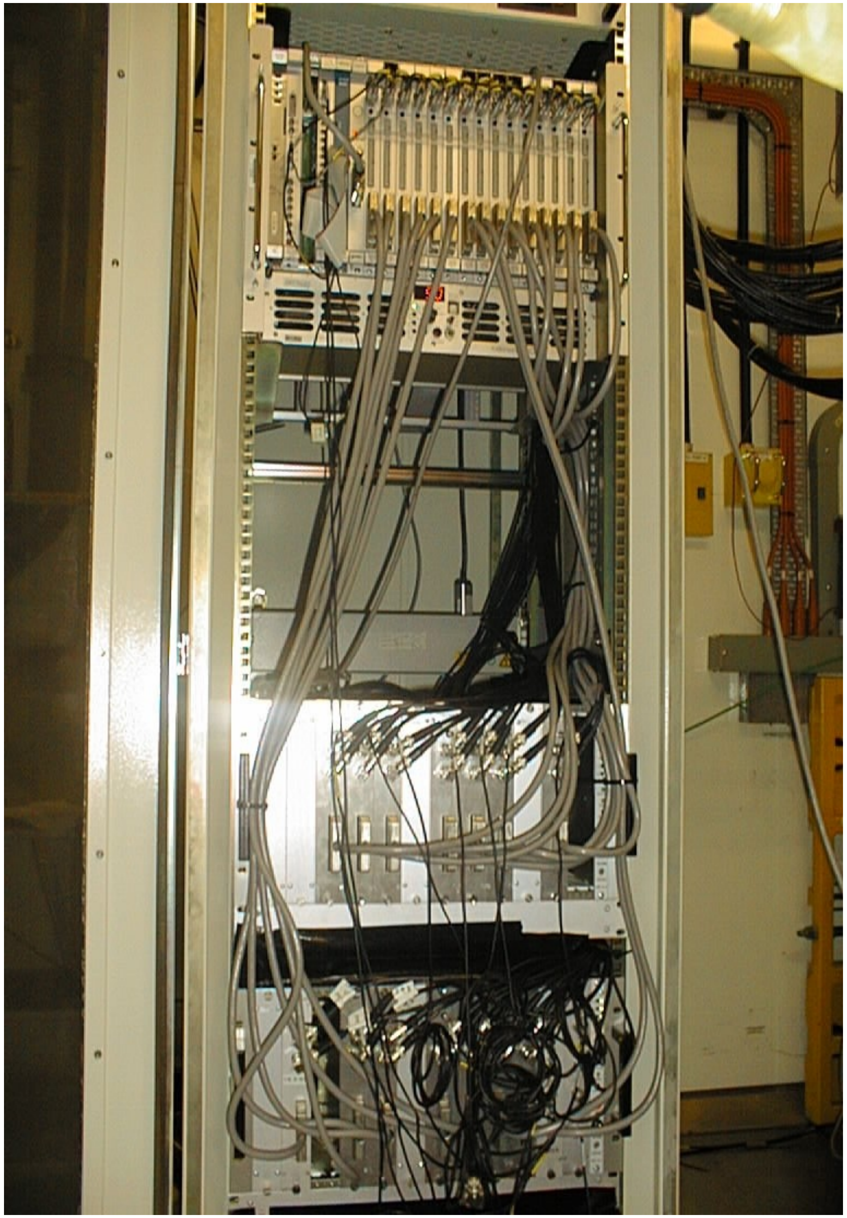
Apart from the detailed work associated with the detector and front-end….

integration into an X-SPRESS based DAQ system was relatively straightforward

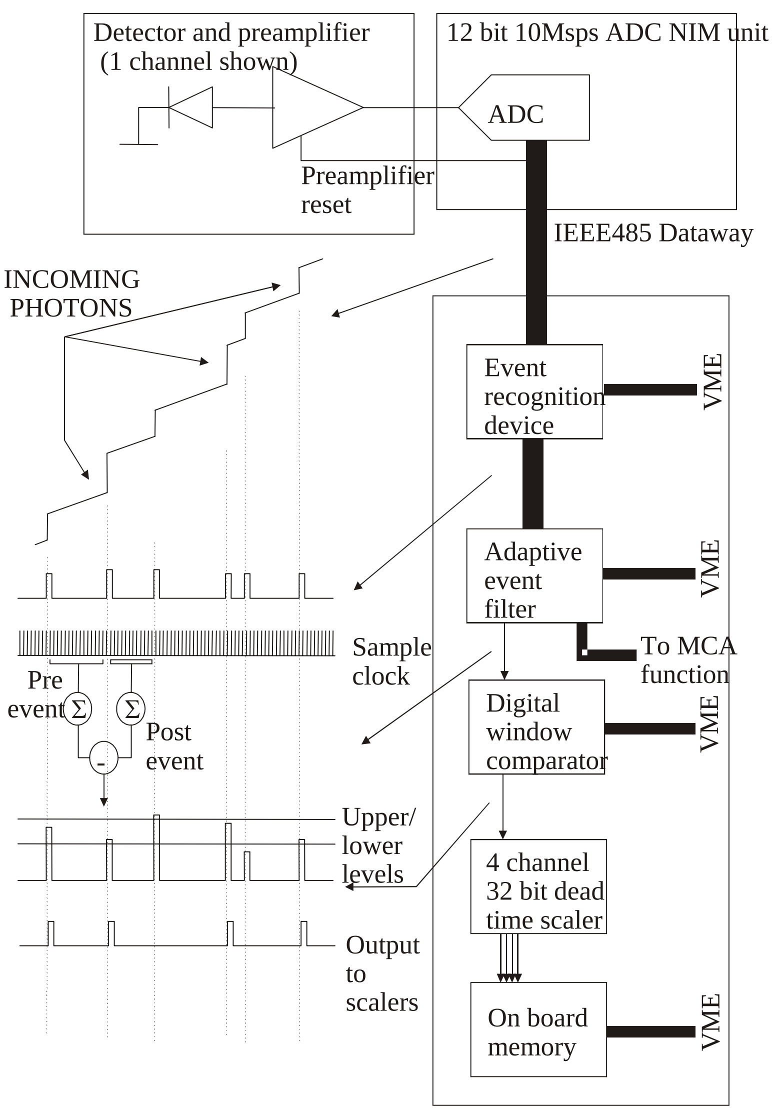
due to the flexibility built into the X-SPRESS system.

Note the flexibility statement

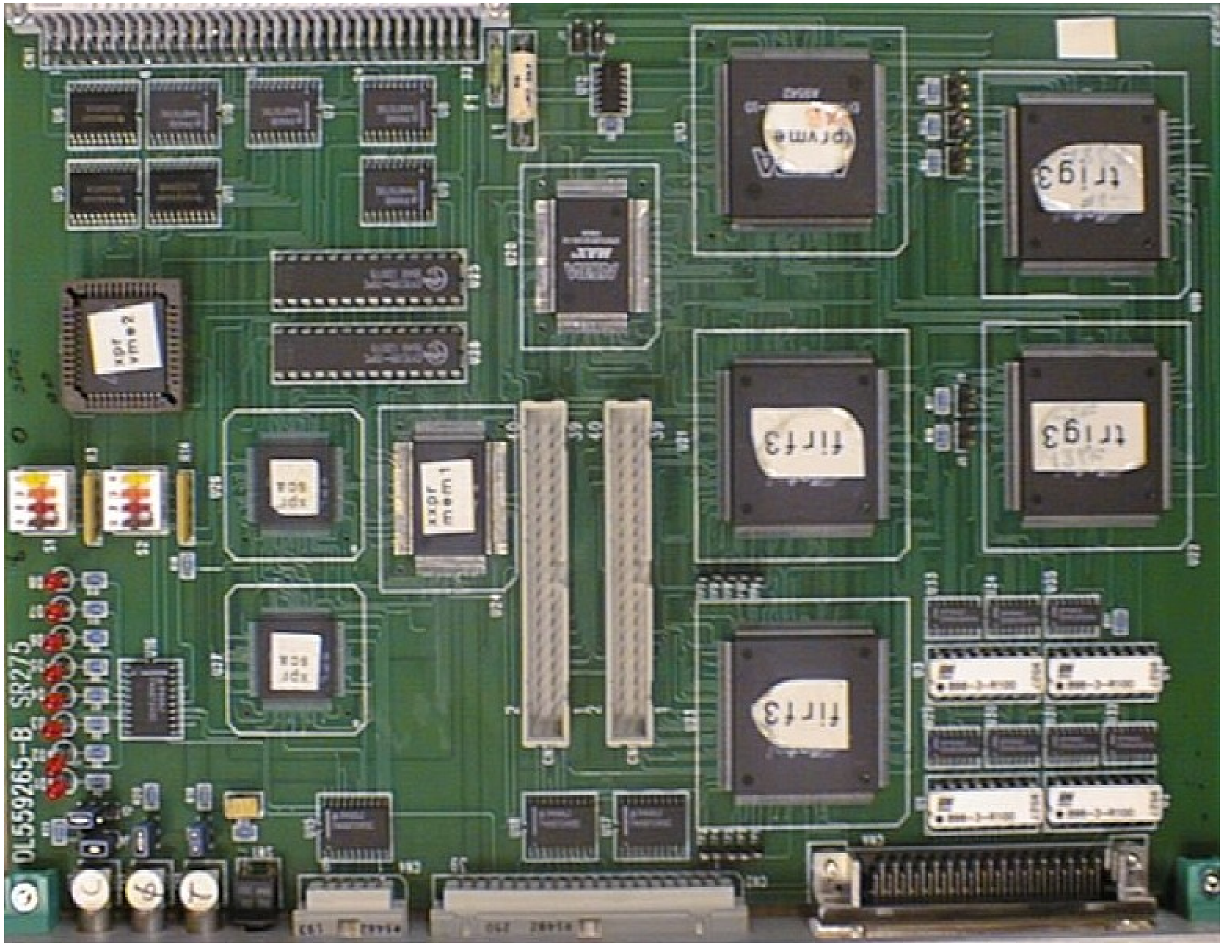
X-SPRESS RACK DAQ SYSTEM



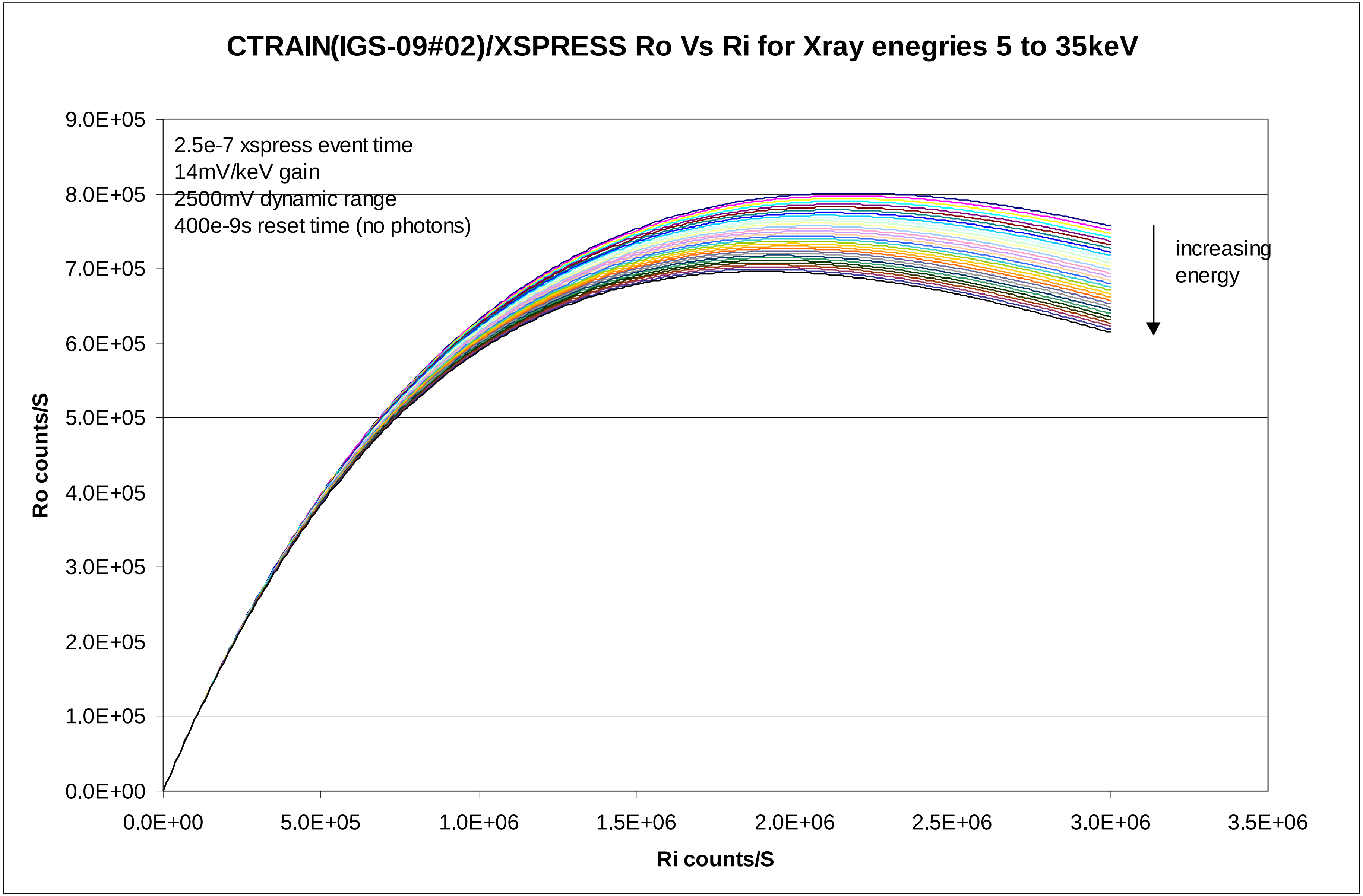
X-SPRESS DATA FLOW



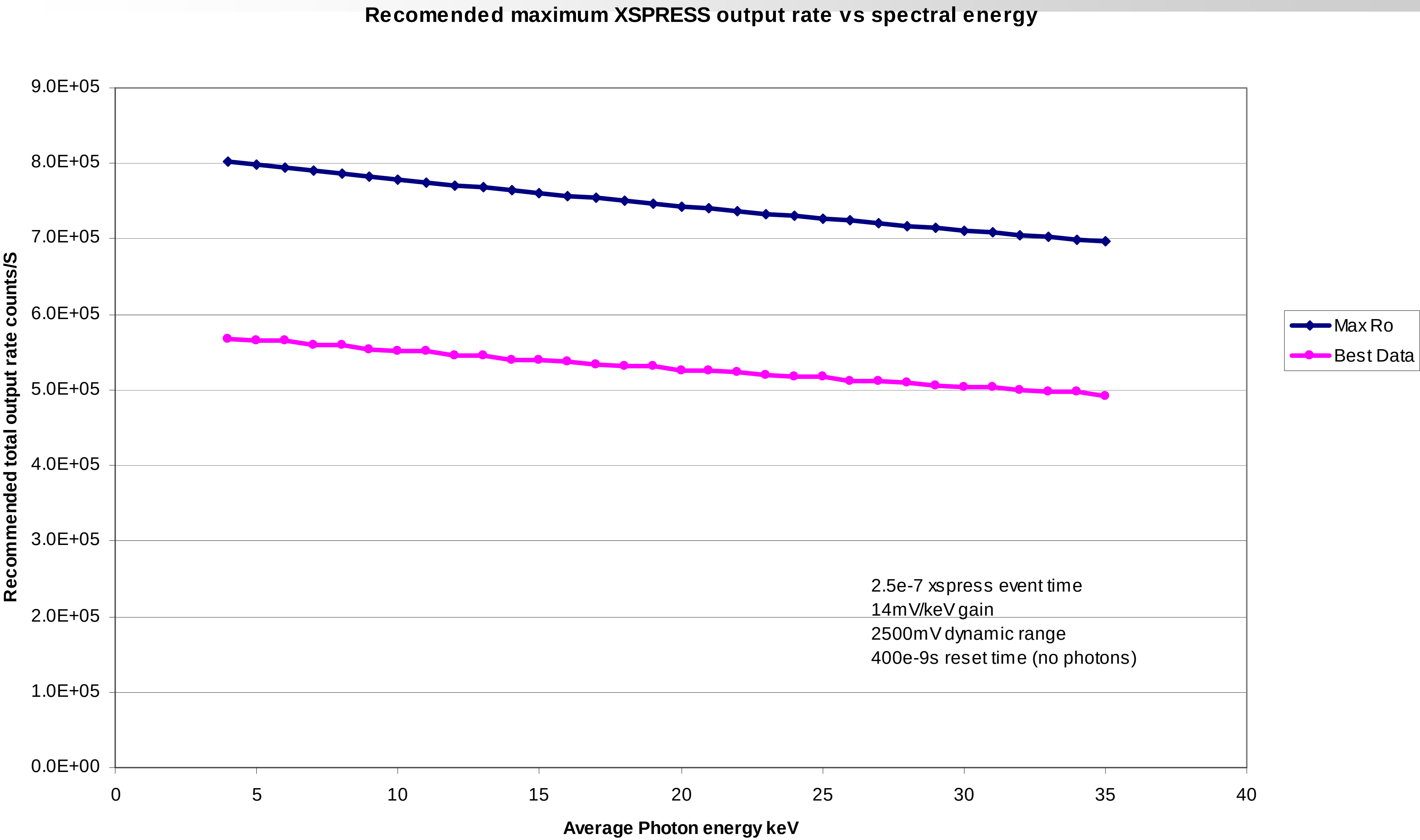
X-SPRESS VME DIGITAL PROCESSOR (CUSTOM BUILT)



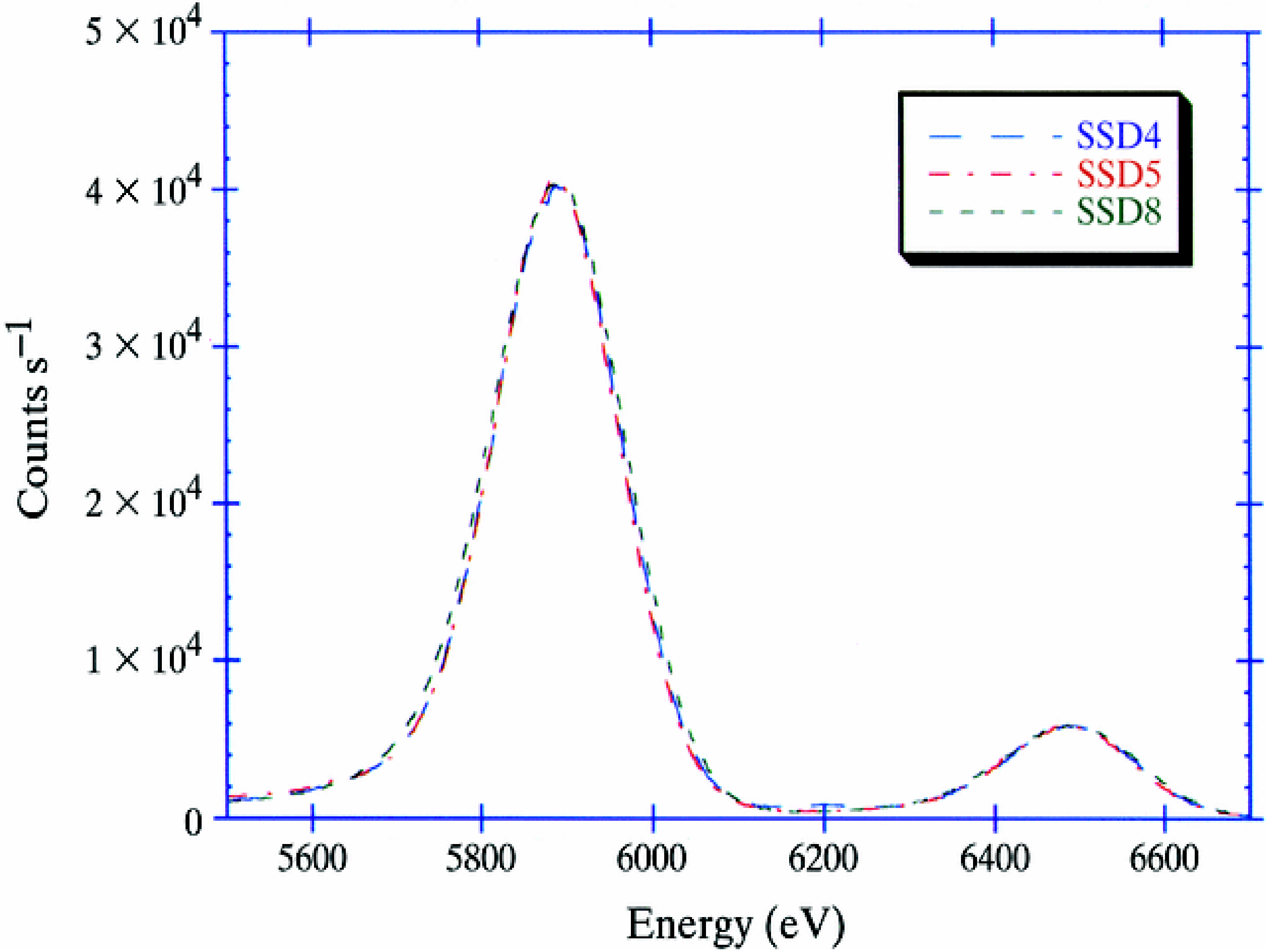
Rate changes with X-ray Energies



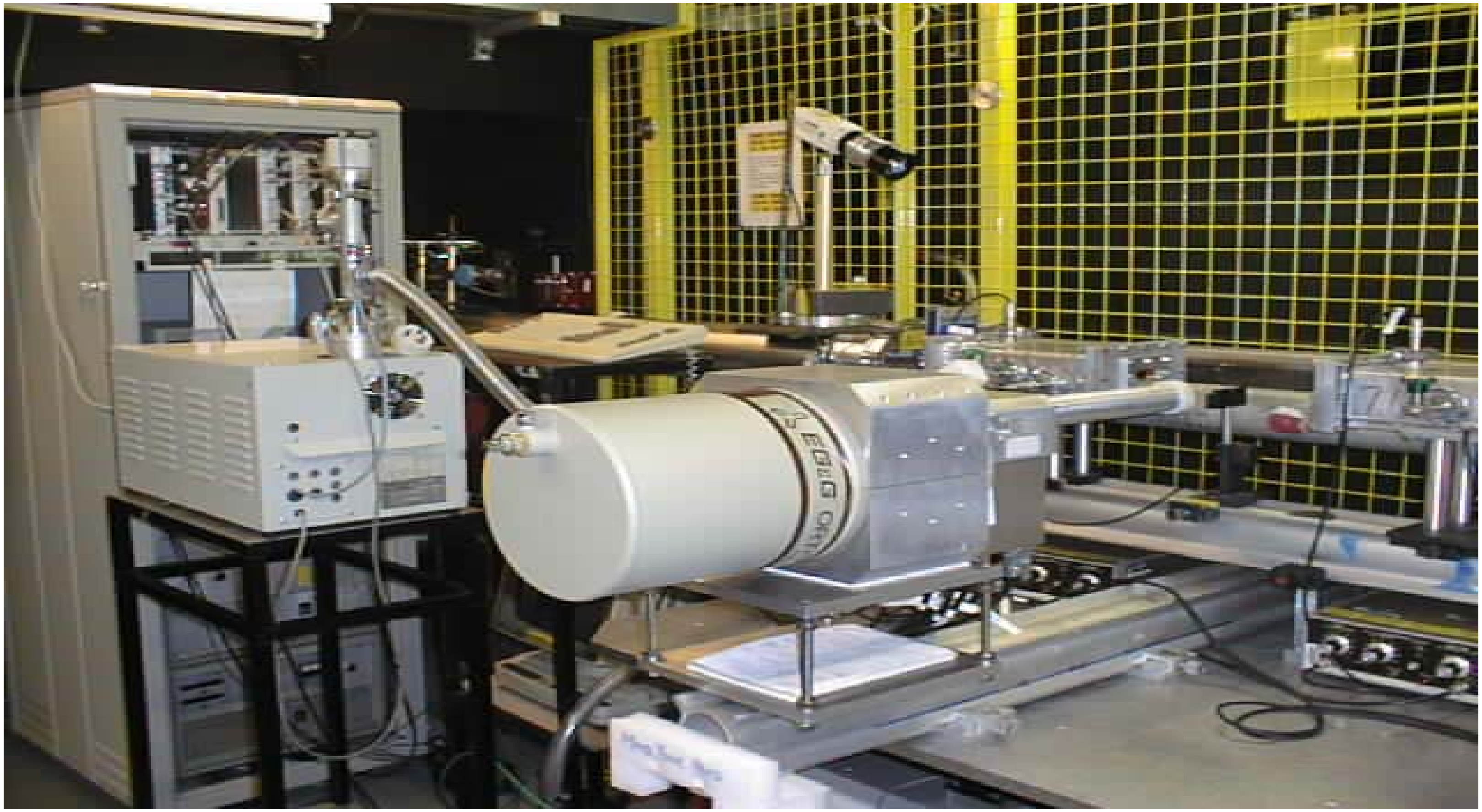
C-TRAIN XSPRESS RATES



Typical Resolution from 9 element C-TRAIN



C-TRAIN Final System on SRS Station 7.1



Also what we haven't done but could do!

XSPRESS is an adaptive system.

It takes as much time as available to obtain information on X-ray pulses.

That information is stored.

So we can change the effective resolution of the detector system on the fly.

Only select very good resolution events near an edge and correct for pile-up and then open up the throughput as the resolution requirements relax above the edge but more photons help statistics.

Why didn’t we do it?

Because as soon as C-TRAIN X-SPRESS was ready it was on beamline taking data.

This is good as it proves that it was needed

But bad for realising the full potential

and increases the development time still further.(difficult to get back)

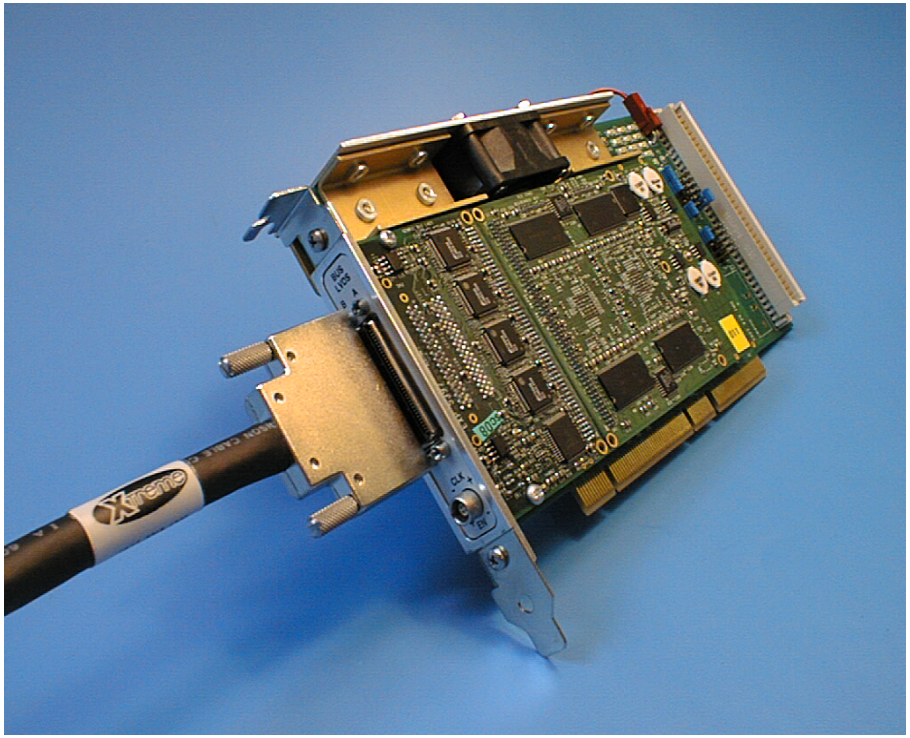
Locks you in to incremental development.

Some people like this!

What next, more safe incremental?

- 4 element C-TRAIN FOR LINE 10 Protein Crystallography Station on SRS
- After that C-TRAIN on DIAMOND?
- DAQ:-
- New Spectral Storage technique to be tested on 16.5 and 7.1 at the SRS.
- X-SPRESS will move to Generic DAQ implementation X-SPRESS2
- This will be a future proofed implementation which will be able to make best use of electronics development as it occurs.

XSPRESS2 Generic DAQ Hardware 2004



- **Currently 18 in service**
- **New batch 10 - 15 modules**

  Particle Physics
- **New Virtex II Digital Front End**
- **New Developments**

  14 bit ADC Front End

  Start with existing 12 bit ADC Front End

  Estimate 4 channels per board of X-SPRESS in GDAQ

Present day incremental and step-change

C-Train XSPRESS shows how you can get there.

But is there another way?

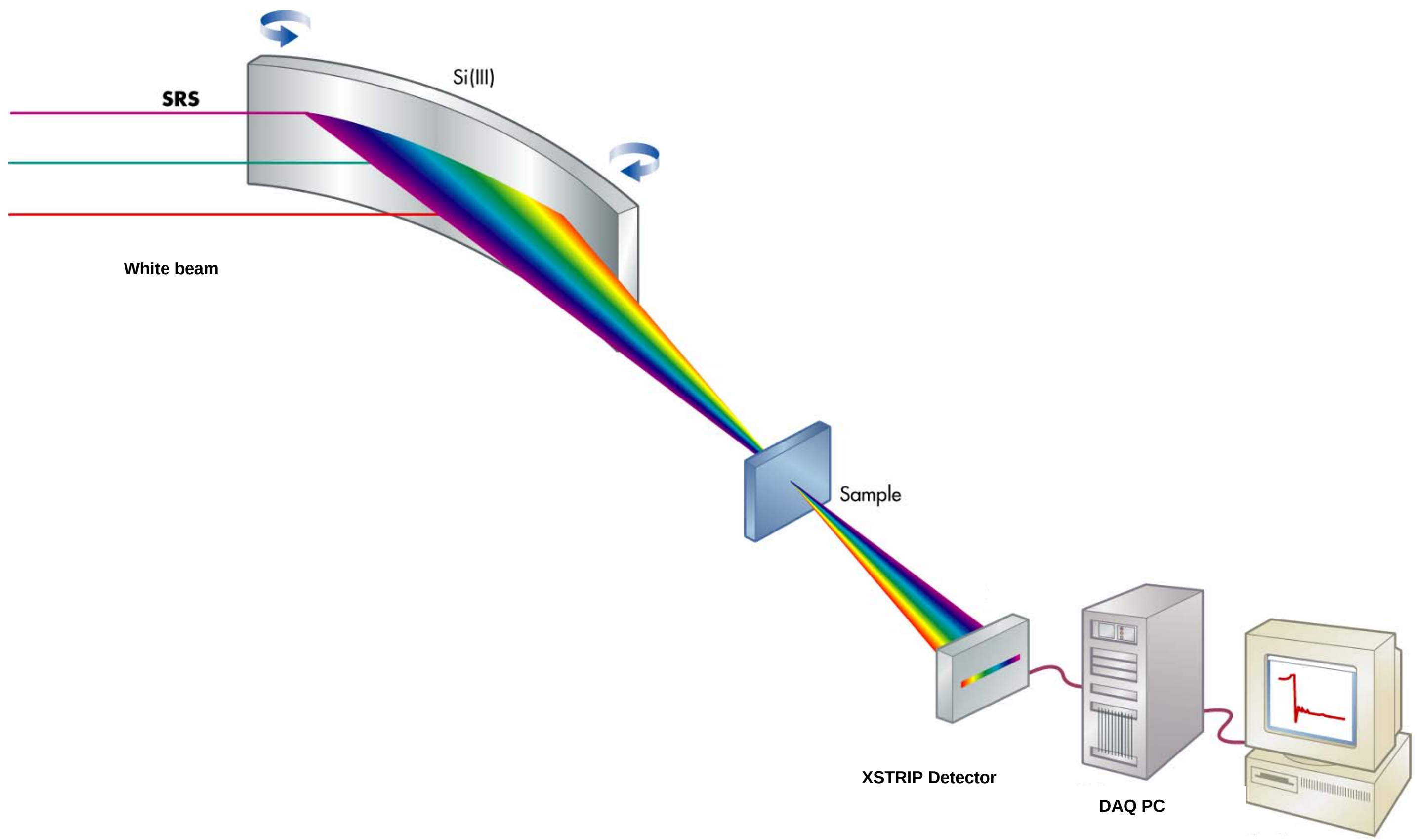
XSTRIP project model

The XSTRIP project was completed in approx:-18 months.

The project was started in May 1999 and taking data in January 2001.

Prototyping had been completed in an 12 month period prior to this borrowing technology and staff from HEP.

Energy Dispersive Experimental set-up



EDE time resolved

Definitions-Why dispersive EXAFS?

- In EXAFS ‘quick’ means a minute or less.

- Most chemical reactions << minute

- Energy Dispersive EXAFS (EDE).

- Currently commercial PDAs or CCDs.

- But for these the vast majority of chemical reactions lie beyond their capability.

XSTRIP outline

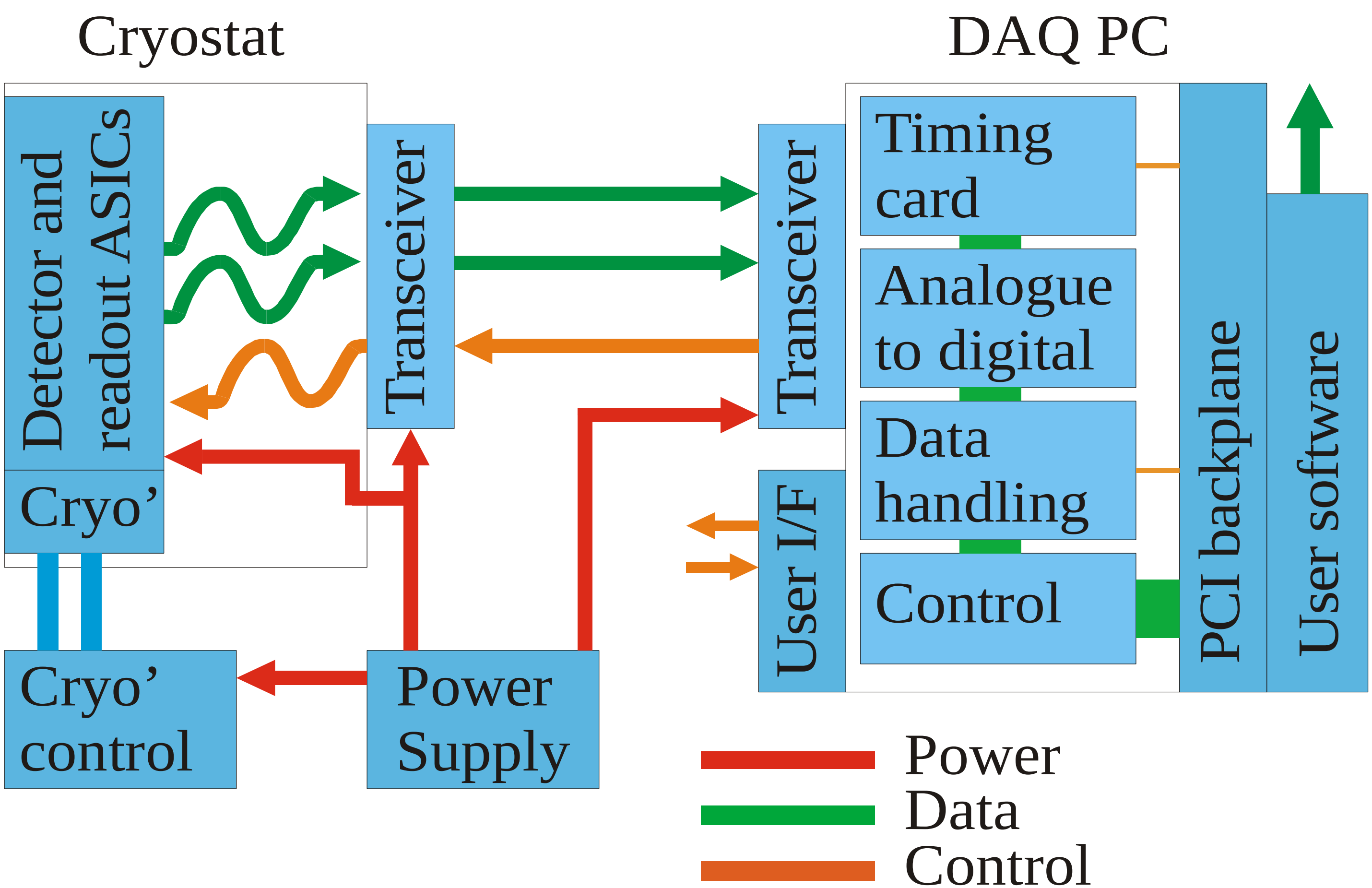
- Custom designed detector system for Energy Dispersed EXAFS

- Detector : 1024 pixel Si mstrip (25 micron pitch)

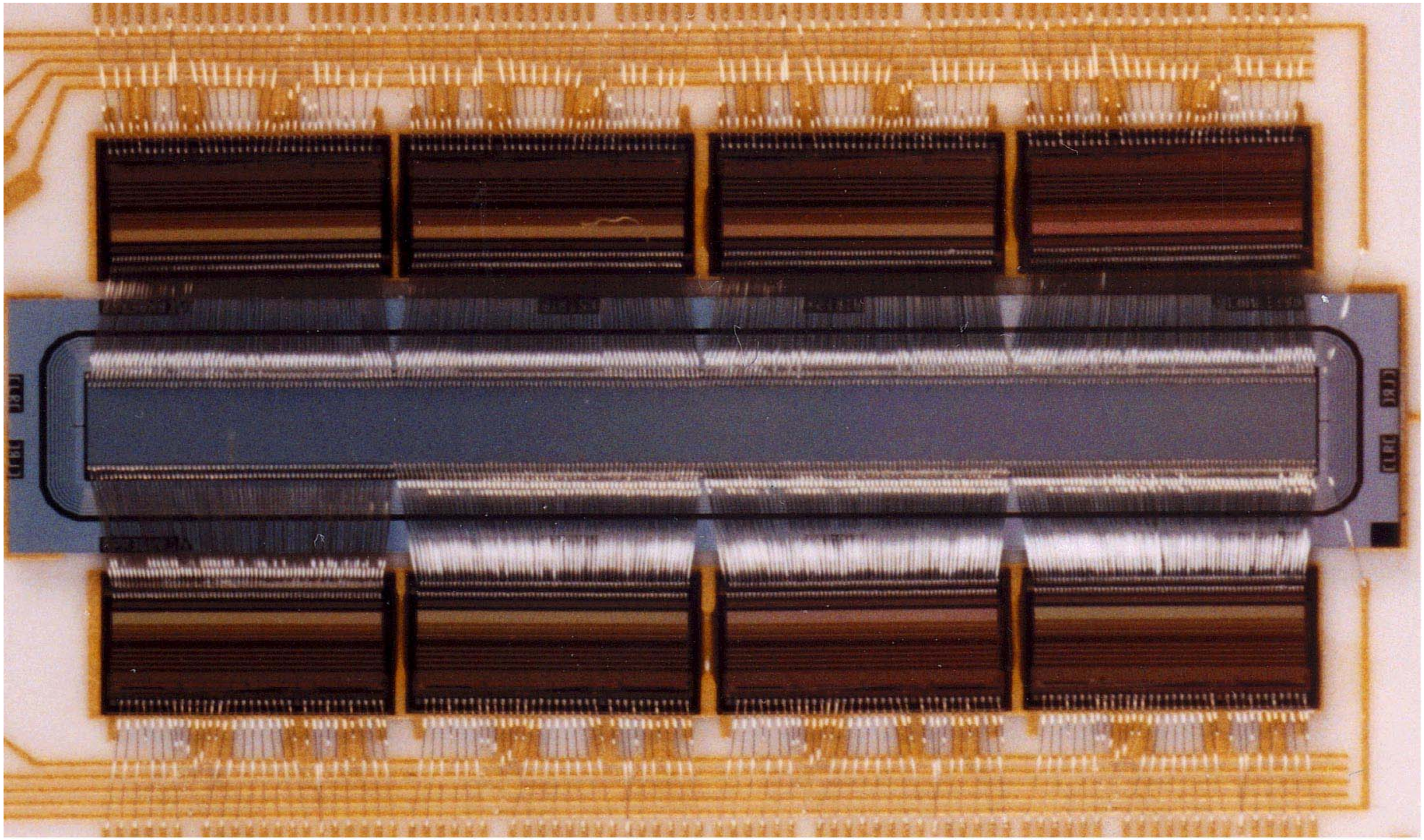
- XCHIP : Front end readout ASIC

- DAQ system: PC based

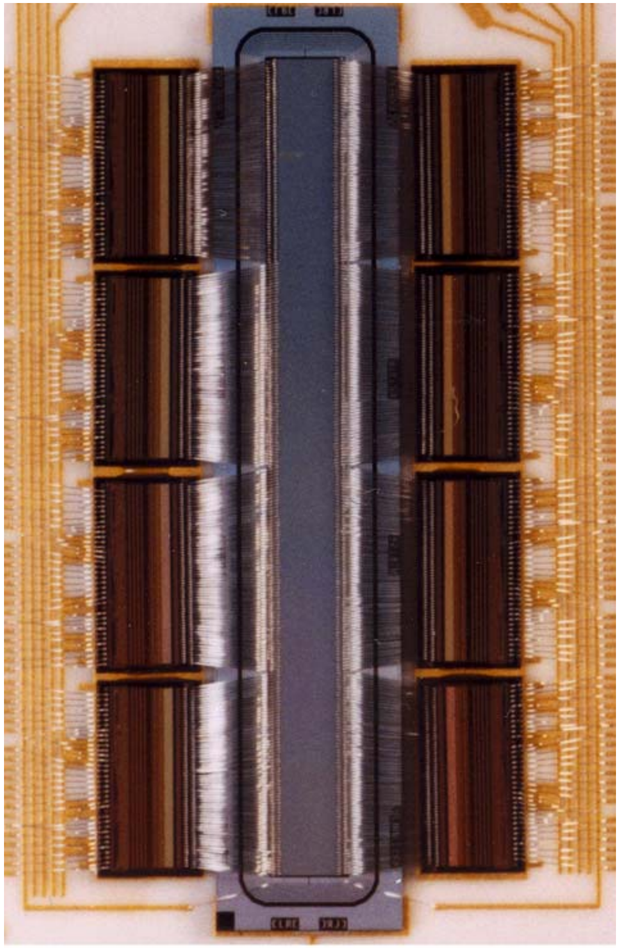
XSTRIP Block Diagram



XSTRIP



Detector Head



- 25mm long, 500μm thick Si detector, 1024, 25 micron by 2.5mm diodes.
- 8 XCHIPs , 0.5 micron C-MOS, 128 channels of charge integrating preamp, 4 readout nodes per chip
- Ceramic MCM with good thermal properties
- DAQ 32 channels of 14 bit ADCs

SR Detector Development XSTRIP

XSTRIP Data Acquisition

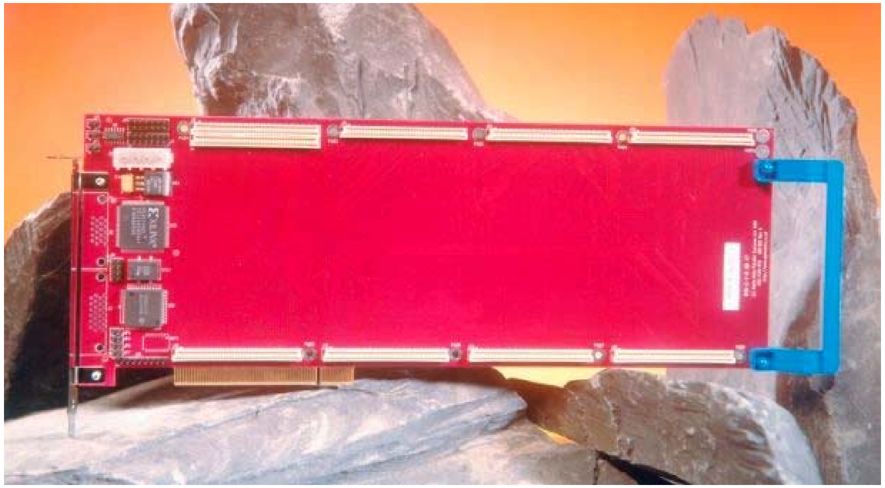
- **Turnkey solution from Sundance.**
- **2 PCI carrier boards handling a total 320MB data per second.**
- **PCI carriers comprise 4 slots.**

  2 x 8 channel 14bit, 5MSPS ADCs.

  1 x VIRTEX FPGA with 8 MB memory.

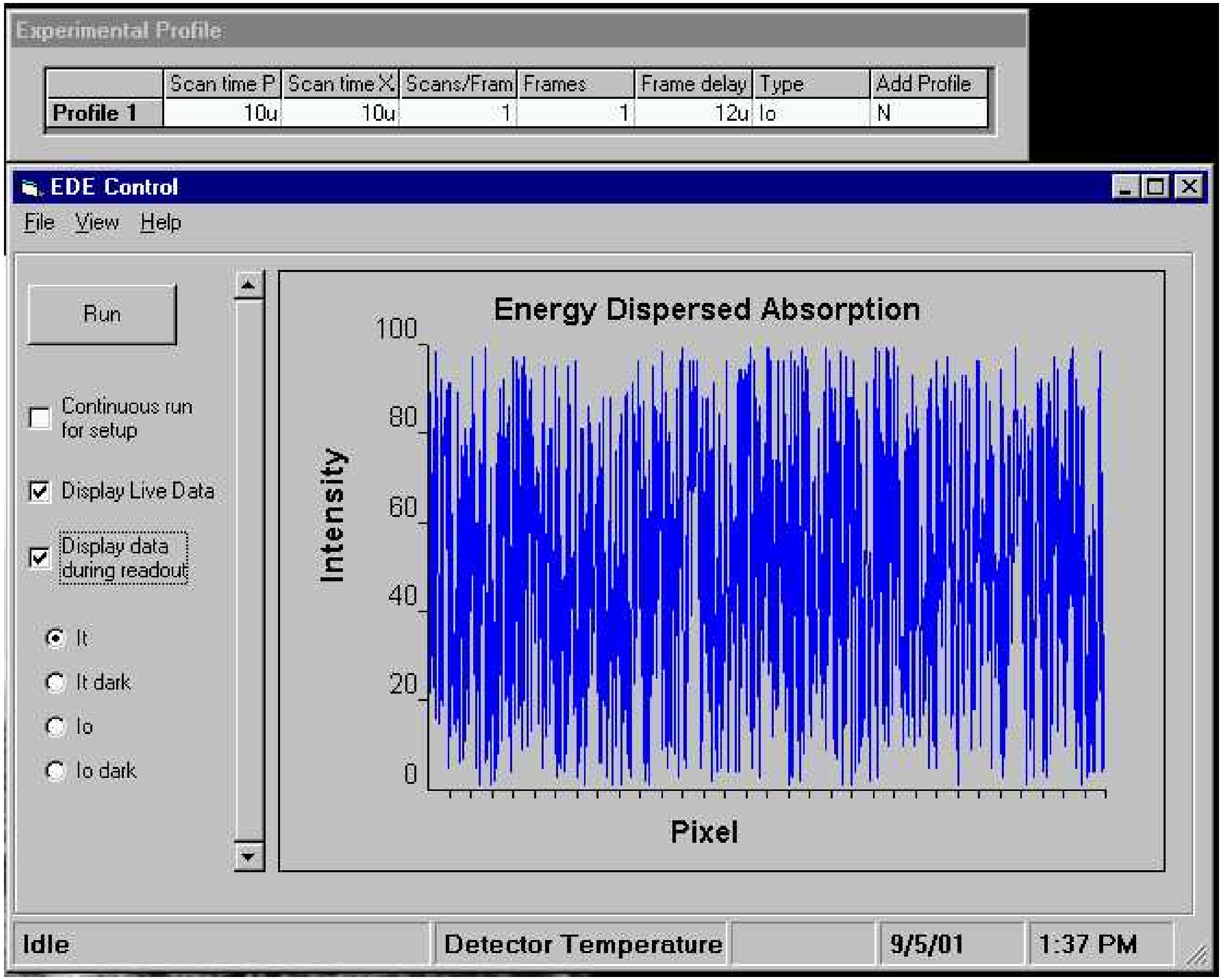
  1 x DSP (Texas Instruments C6x family).

XSTRIP SUNDANCE DAQ



Courtesy
Sundance

Software for XSTRIP



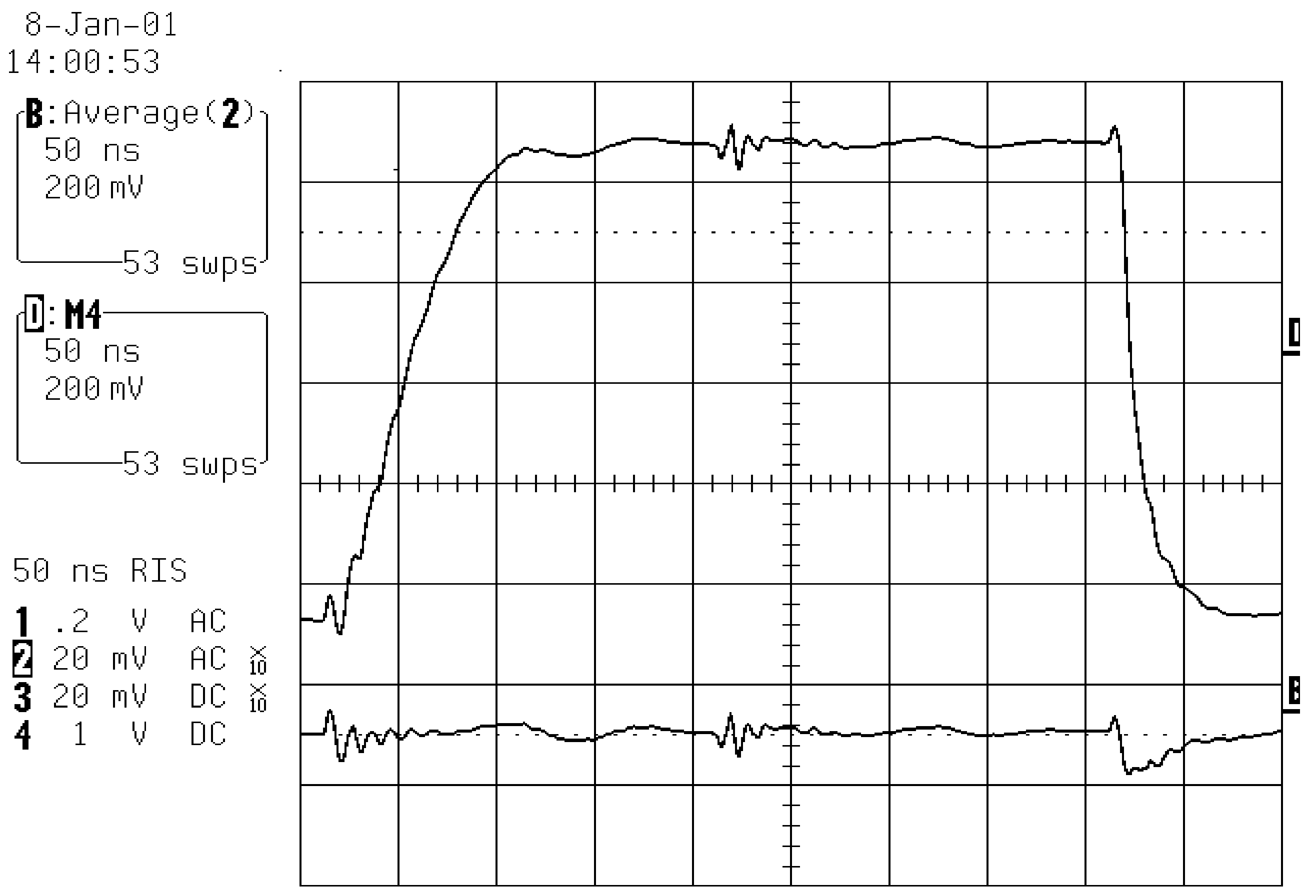
- Profiles
- TCP/IP interface
- Interface to station macros

Meeting the specification

Parameter	**Specification**	***1.1.1 Actual***	**On target**
Maximum photons	> 2.5 x 10^9 photons / pixel	4.5 x 10^9 (@15keV)	✓
Integration time	10μs minimum	1us minimum	✓
Linearity	< 0.2%	0.04%	✓
Readout Efficiency	>75%	90% at 10 μs	✓
Efficiency	>50% for the whole system	60%	✓
Dark Current	<10% over maximum integration period	0.5%	✓
Radiation Resistance	Not specified	Some non-fatal damage observed	✓
Energy Range	5-25 keV	Tested 7-15 keV	✓

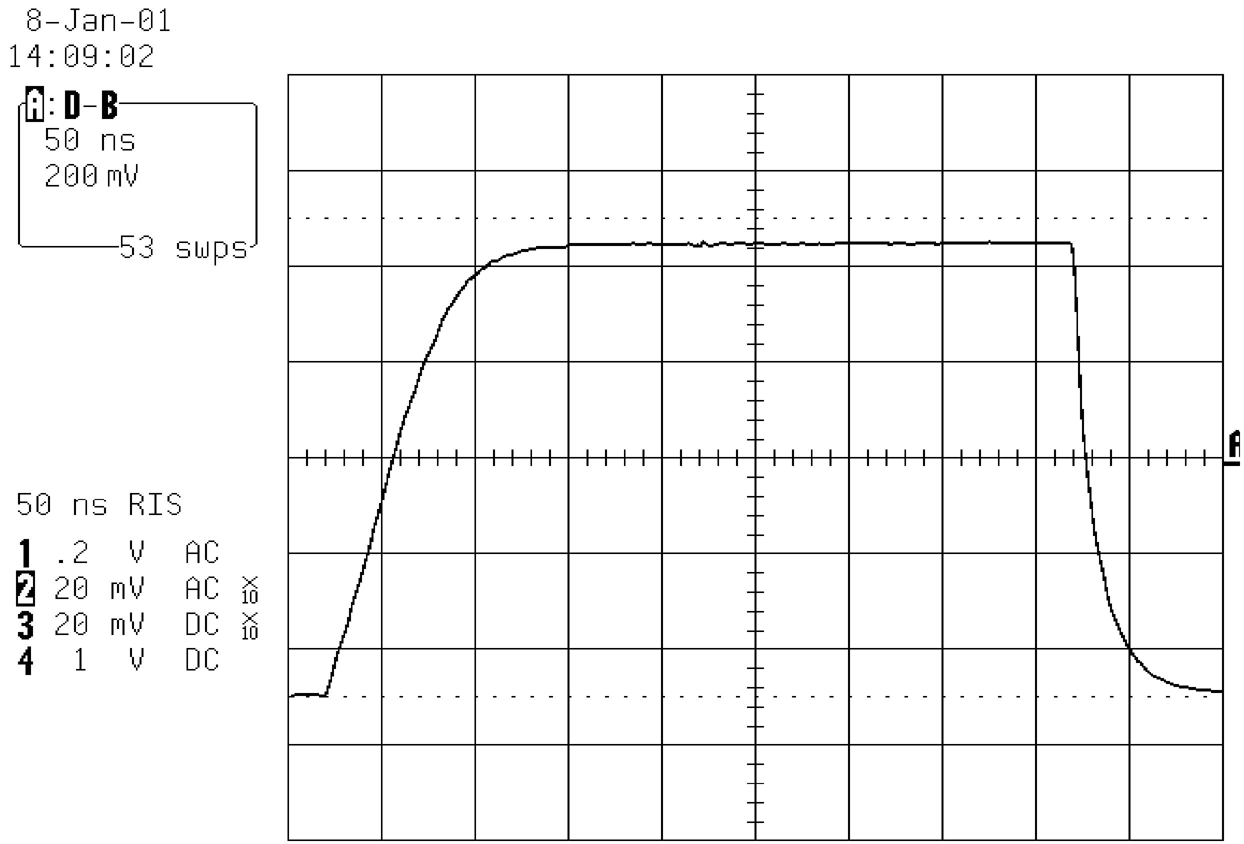
XSTRIP Readout

A1 (lower) and A2 (upper) voltages.

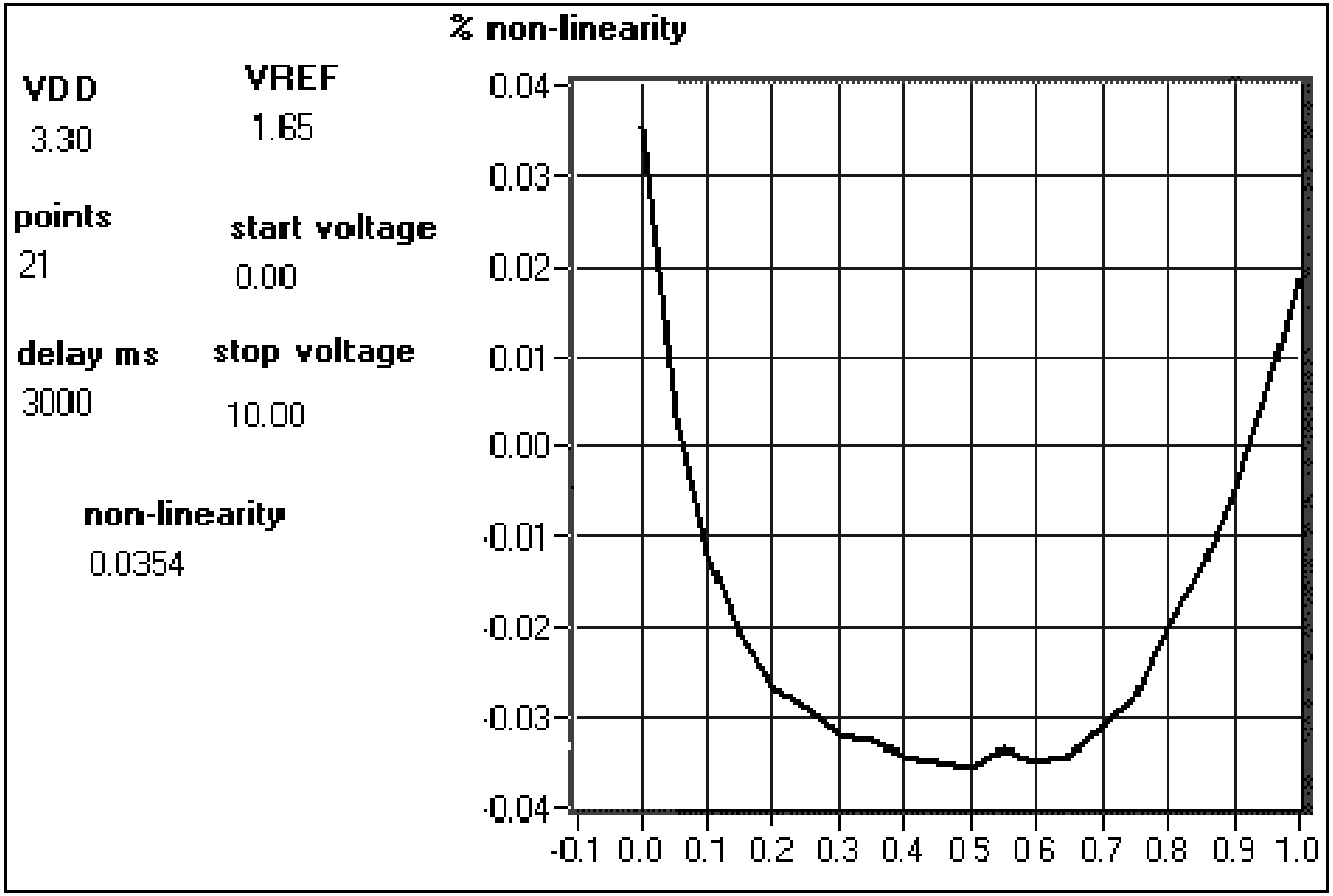


XSTRIP OUTPUT Differential

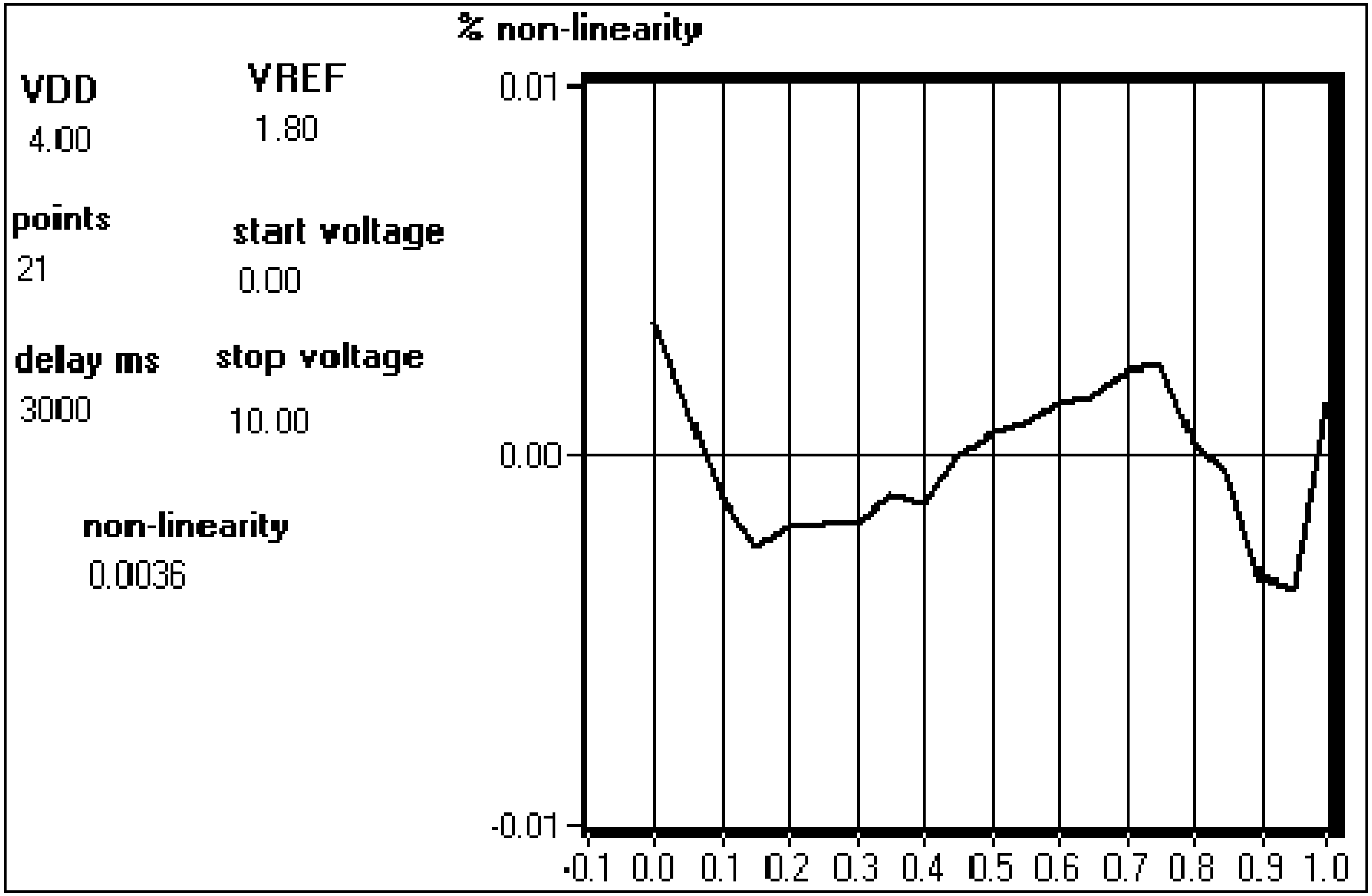
A1-A2 voltage : rise time ~150ns, fall-time ~80ns (to ~0.1% accuracy)



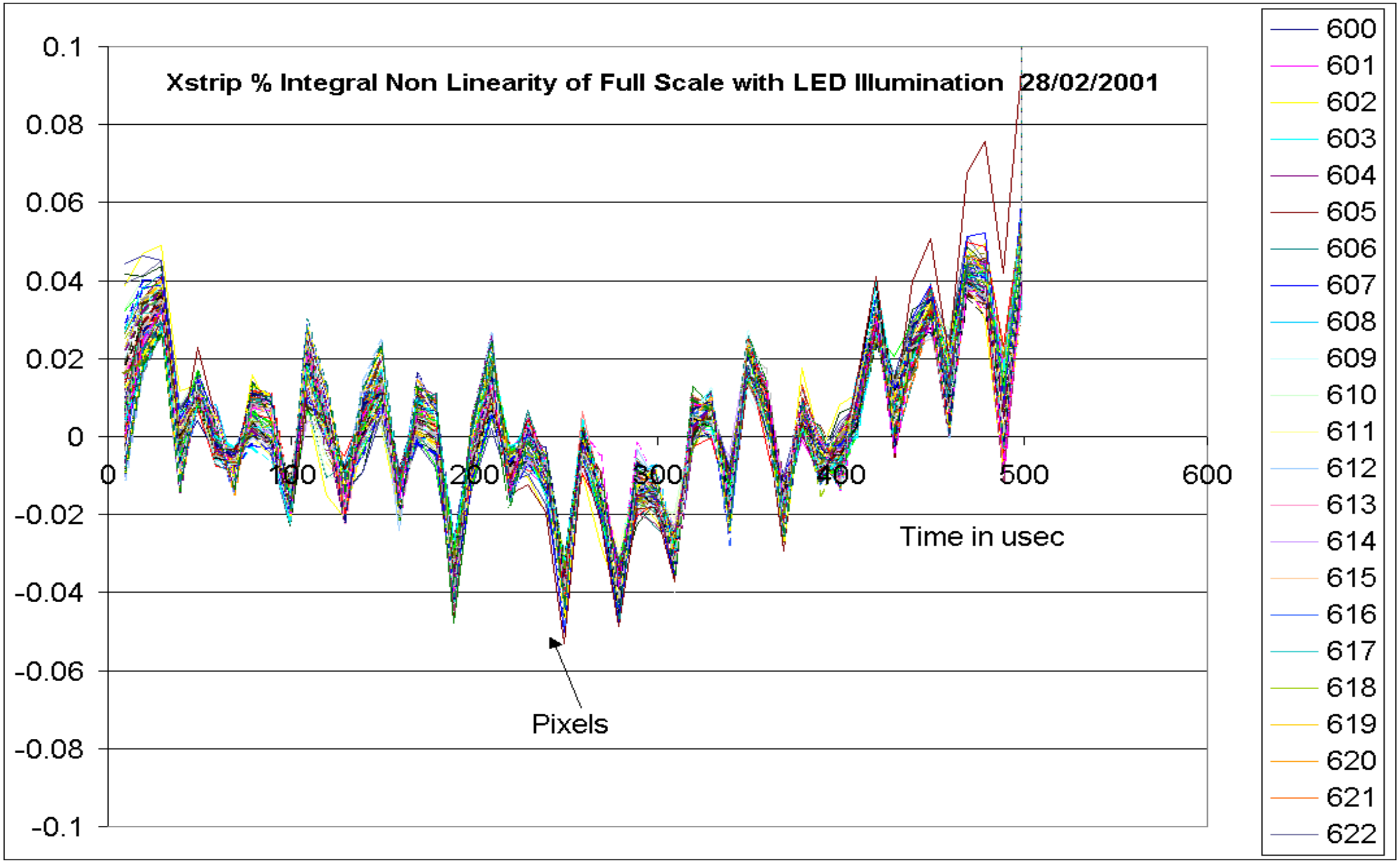
Optimisation with operating voltage



Optimisation with operating Voltage



Testing with detector



XSTRIP

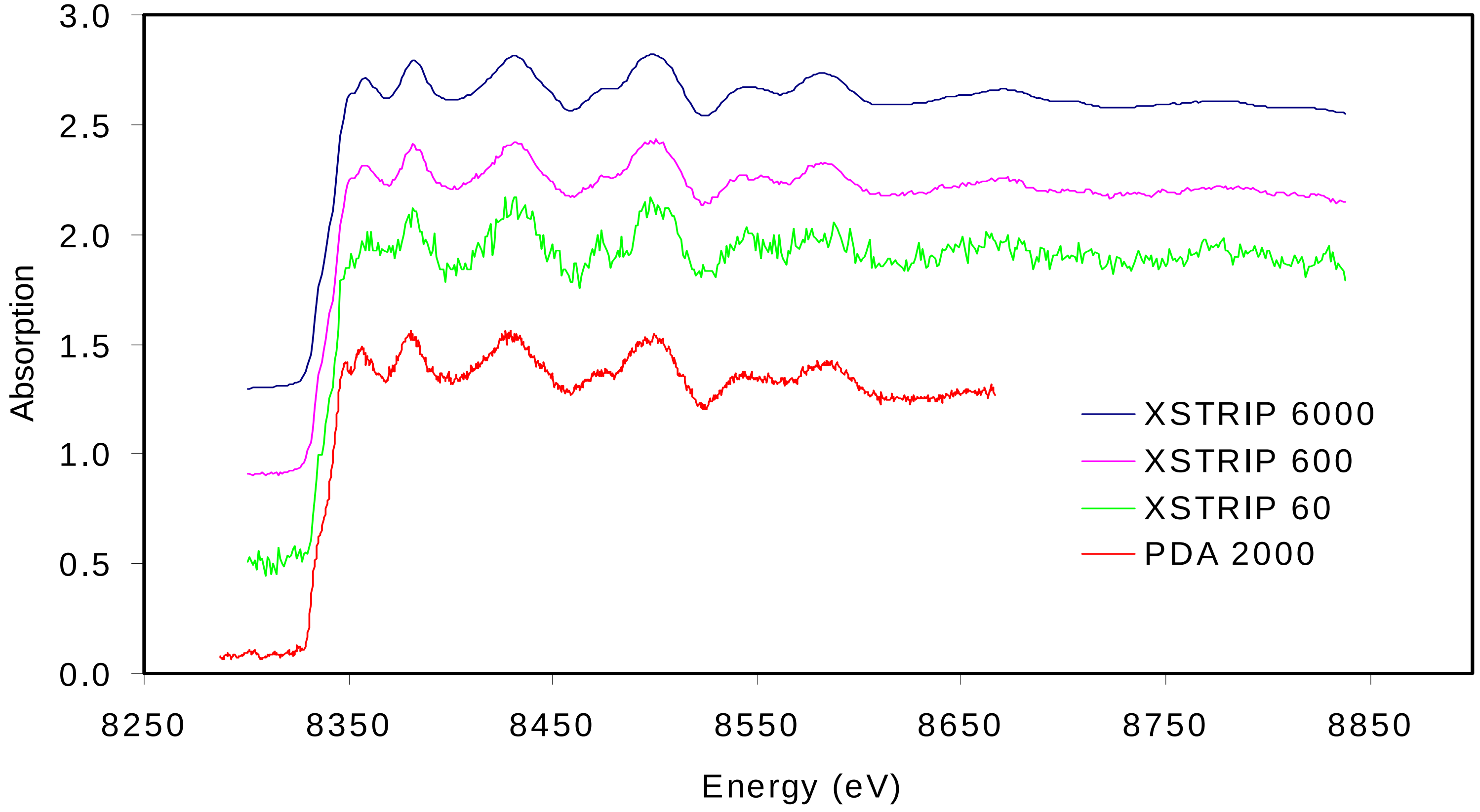


Figure 3a: 5 μm Ni foil

XSTRIP

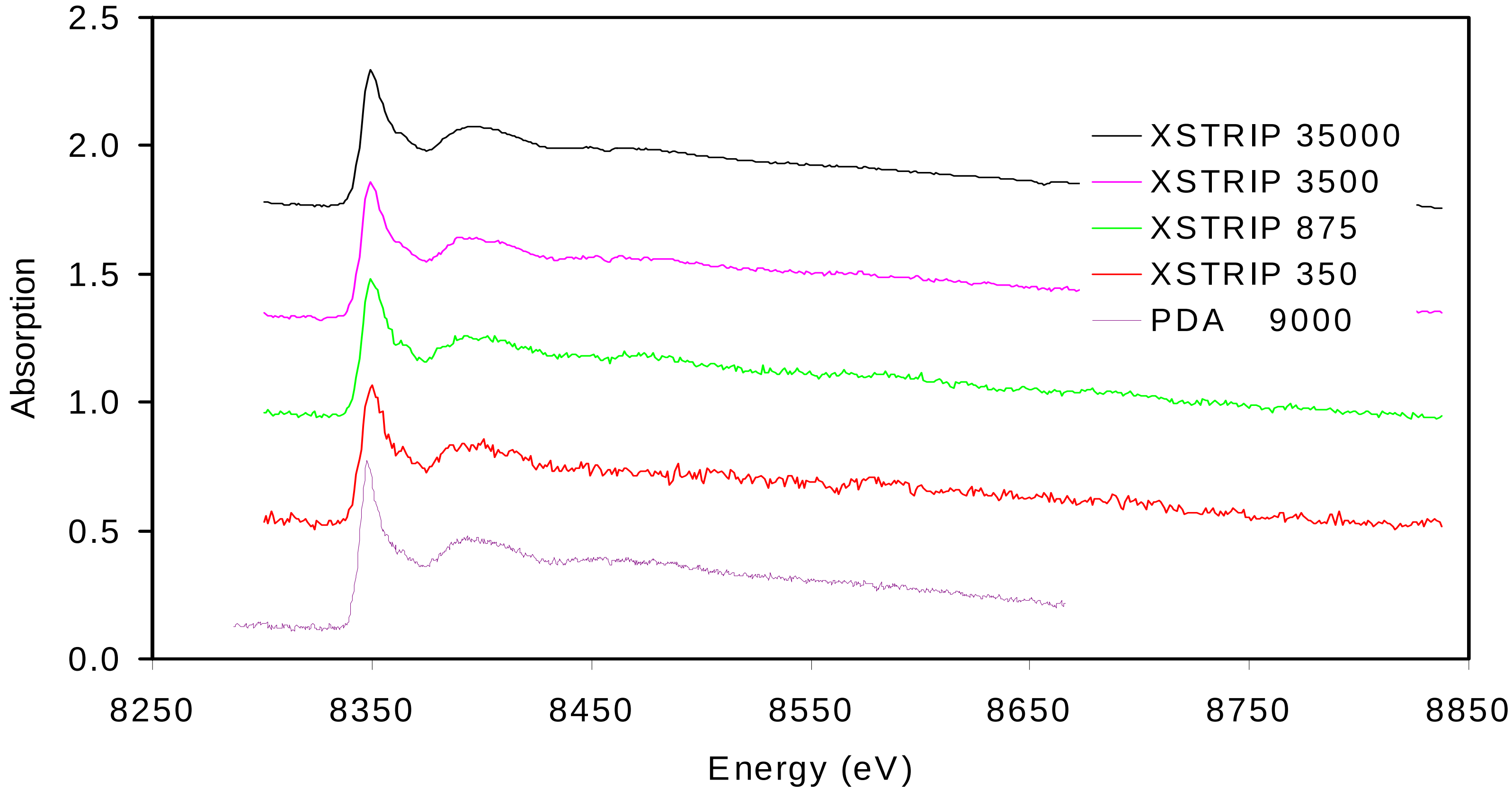
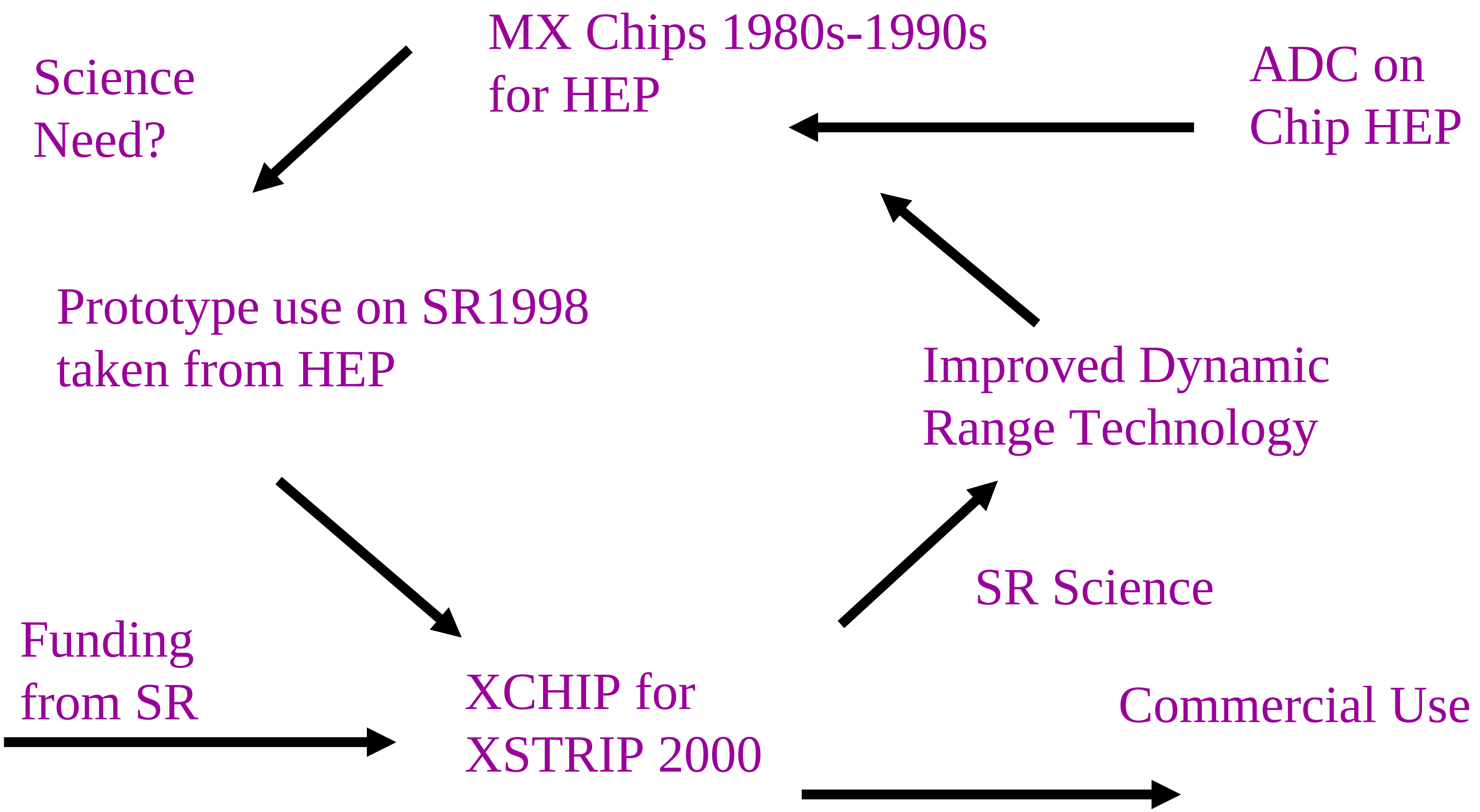


Fig 3b 100 mM NiCl2 solution

XSTRIP project methodology



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Conclusion of present examples

Incremental developments are OK but not radical enough to close the gaps.

(you do the best that you can with what you have)

C-TRAIN X-SPRESS born out of this.

Building in re-use and feedback to the place where the technology came from is a good idea.

XSTRIP is fast but not fast enough for science.

However it is fast enough to study beam instabilities

If you want data on the millisecond to microsecond timescale you need a beam stable to that. (or a reliable way of measuring and correcting it)

The Future (near-term and further away)

The future breaks into two areas:-

NEAR-TERM

Things that we can do and only need funding to achieve.

development- mostly engineering

FURTHER AWAY

things that we don't know how to do

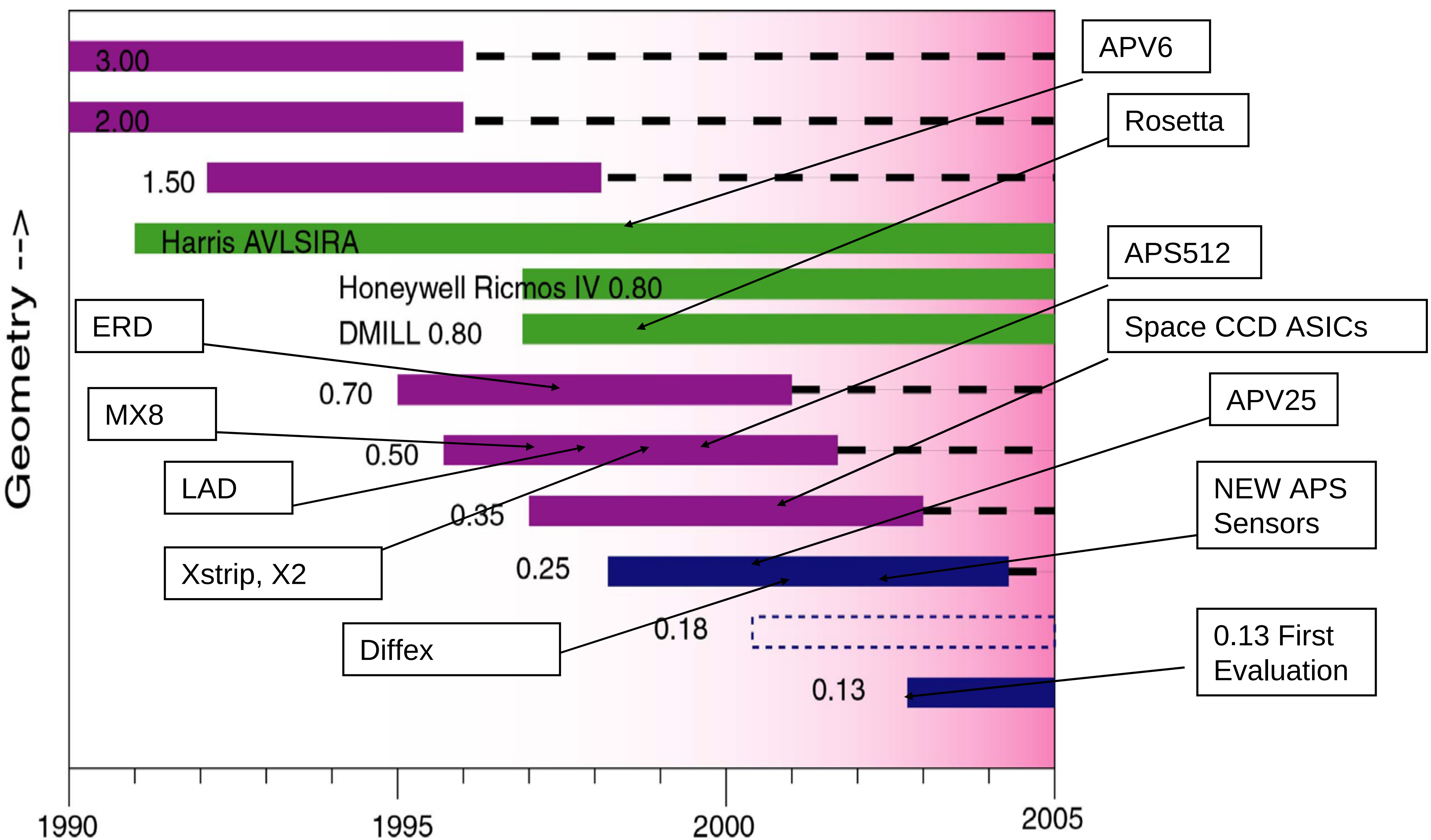
research-a mixture of science, engineering and time

The Future (near-term and further away)

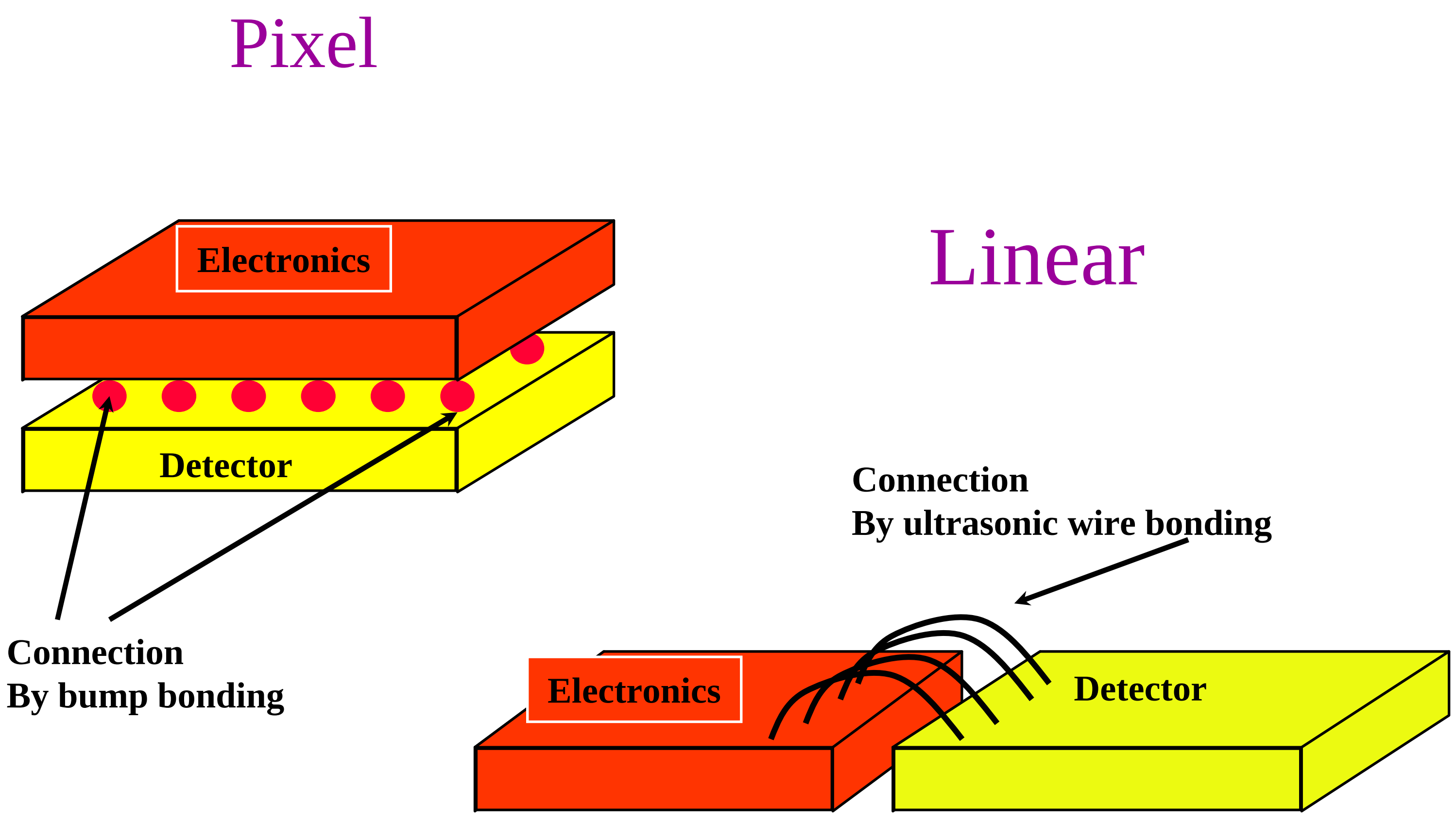
Both near and long term futures rely on microlectronics and probably involve pixellated detectors of one form or another.

The days of CCDs and phosphor screens are numbered.

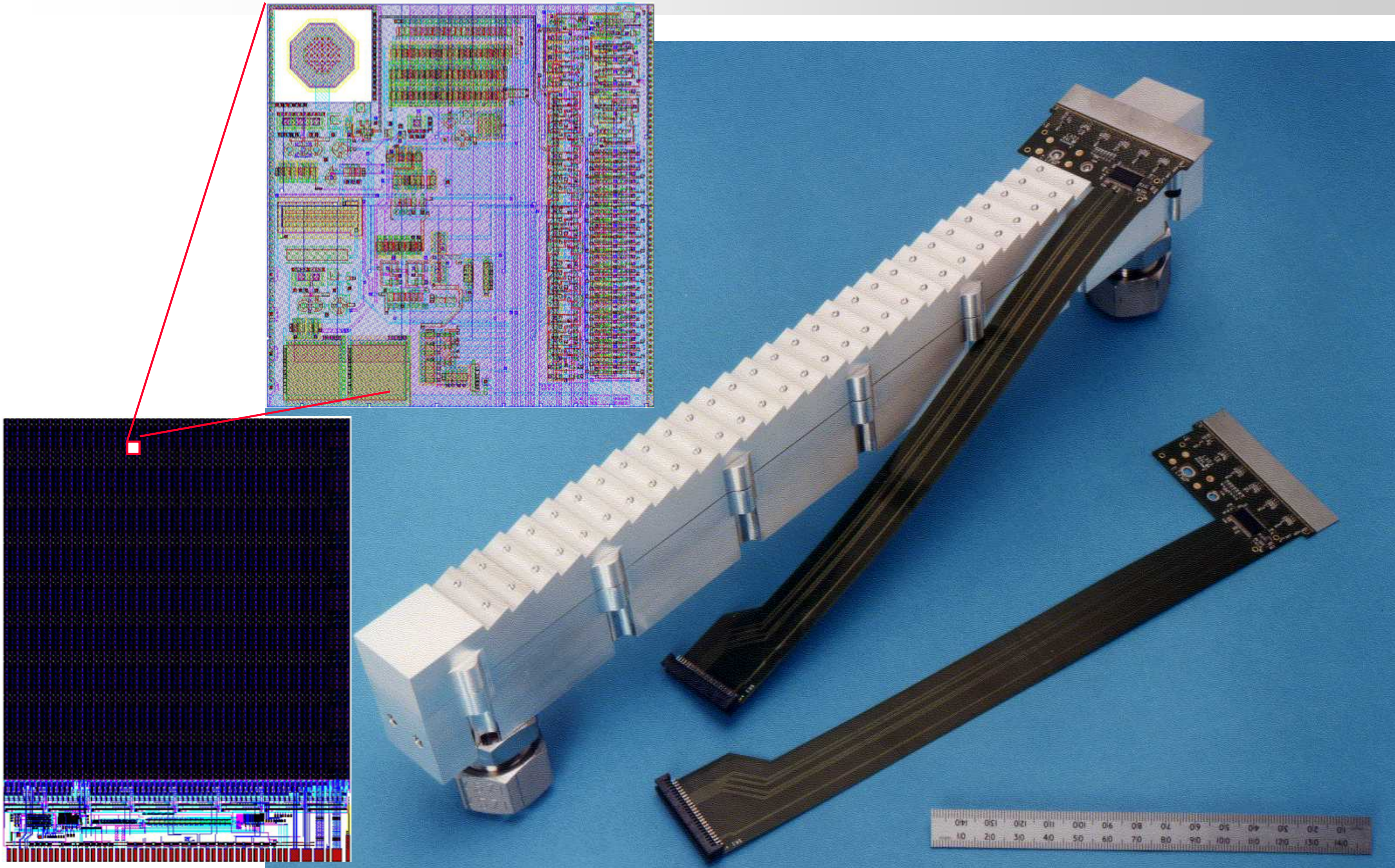
Current and future near term Si strip and pixel detectors rely on microelectronics



Linear and Pixel Solid State Detectors Hybrid.



SR Detector Development Si Pixels



Photon counting (4.10^9/pix),
2d(150µm) 4-25keV,
1MHz/pixel

Issues with Pixels

Bump Bonding

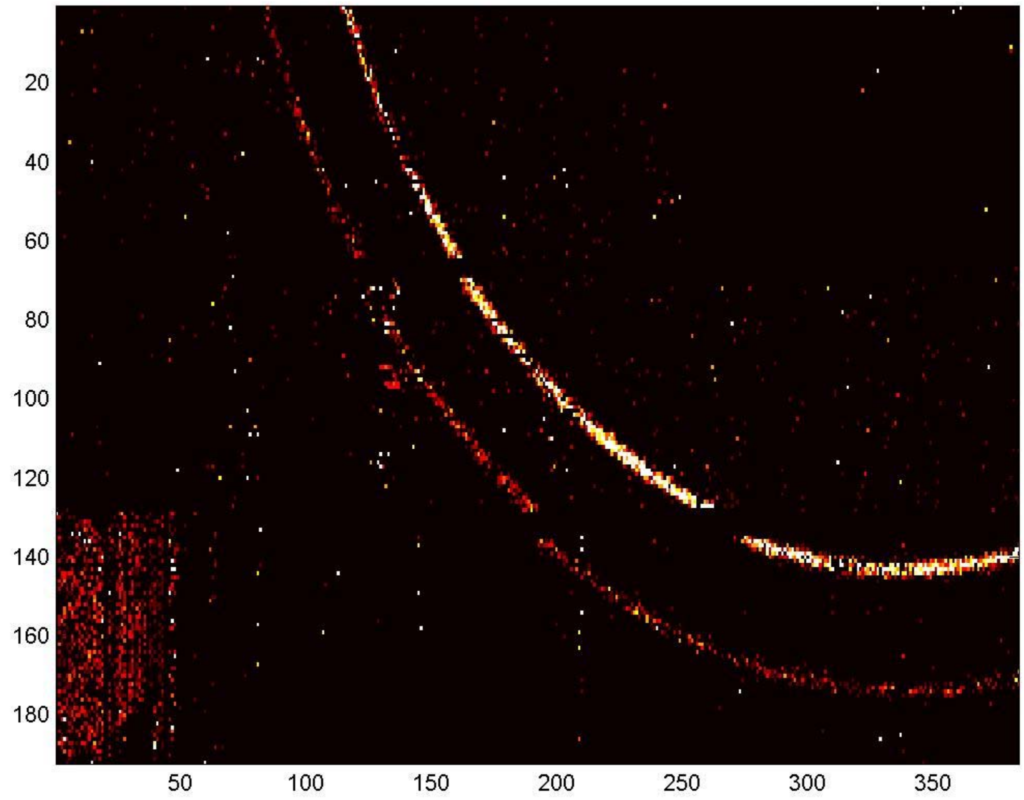
Not stable for small numbers.

It can be done and has been done (mobile phones and Computers)

But if critical to both HEP and SR then we need to set-up a facility which can be dedicated to our needs.

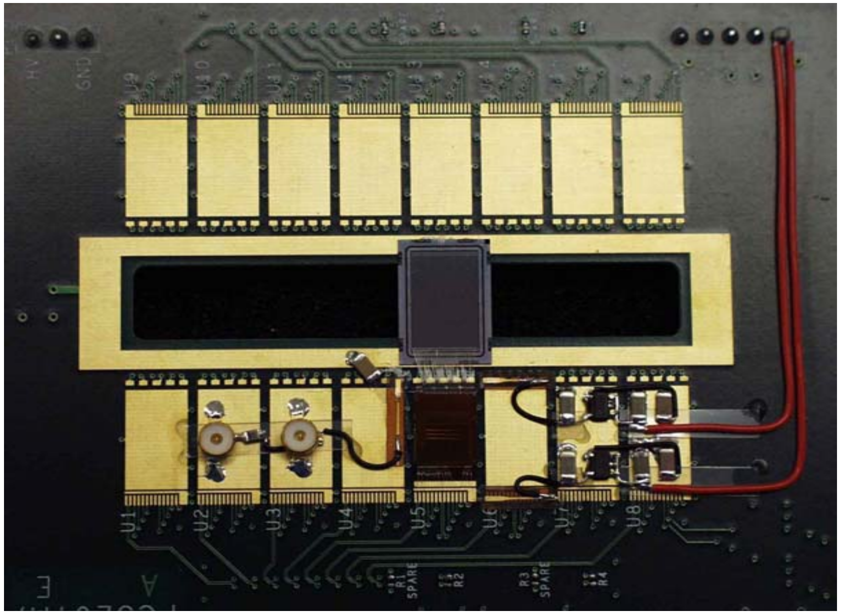
This issue is near-term and has been near-term since the early 1990’s

SR Detector Development Si Pixels

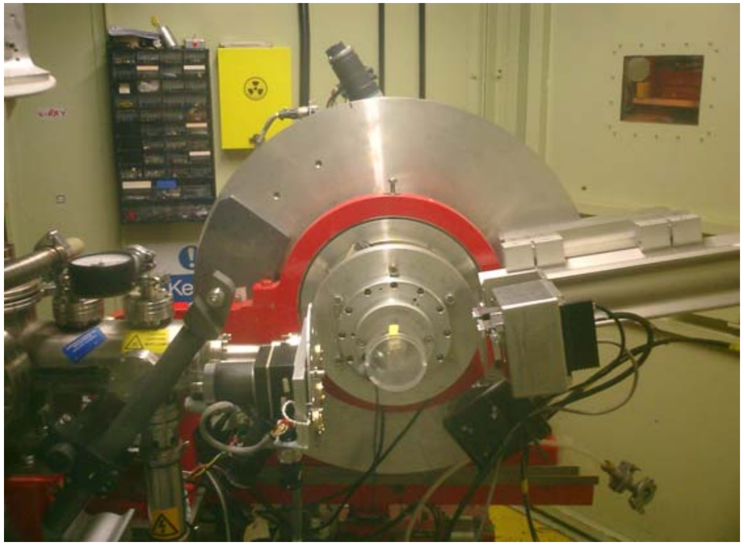


DIFFEX

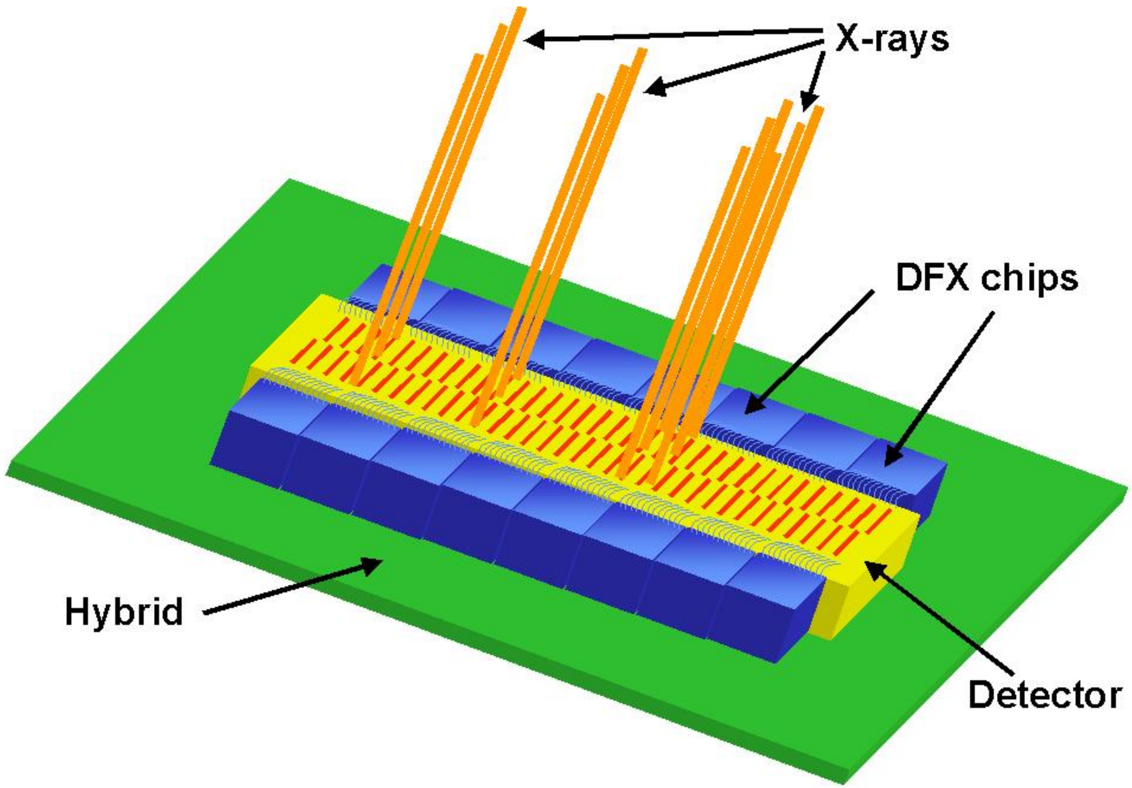
Photon counting can give you energy resolution



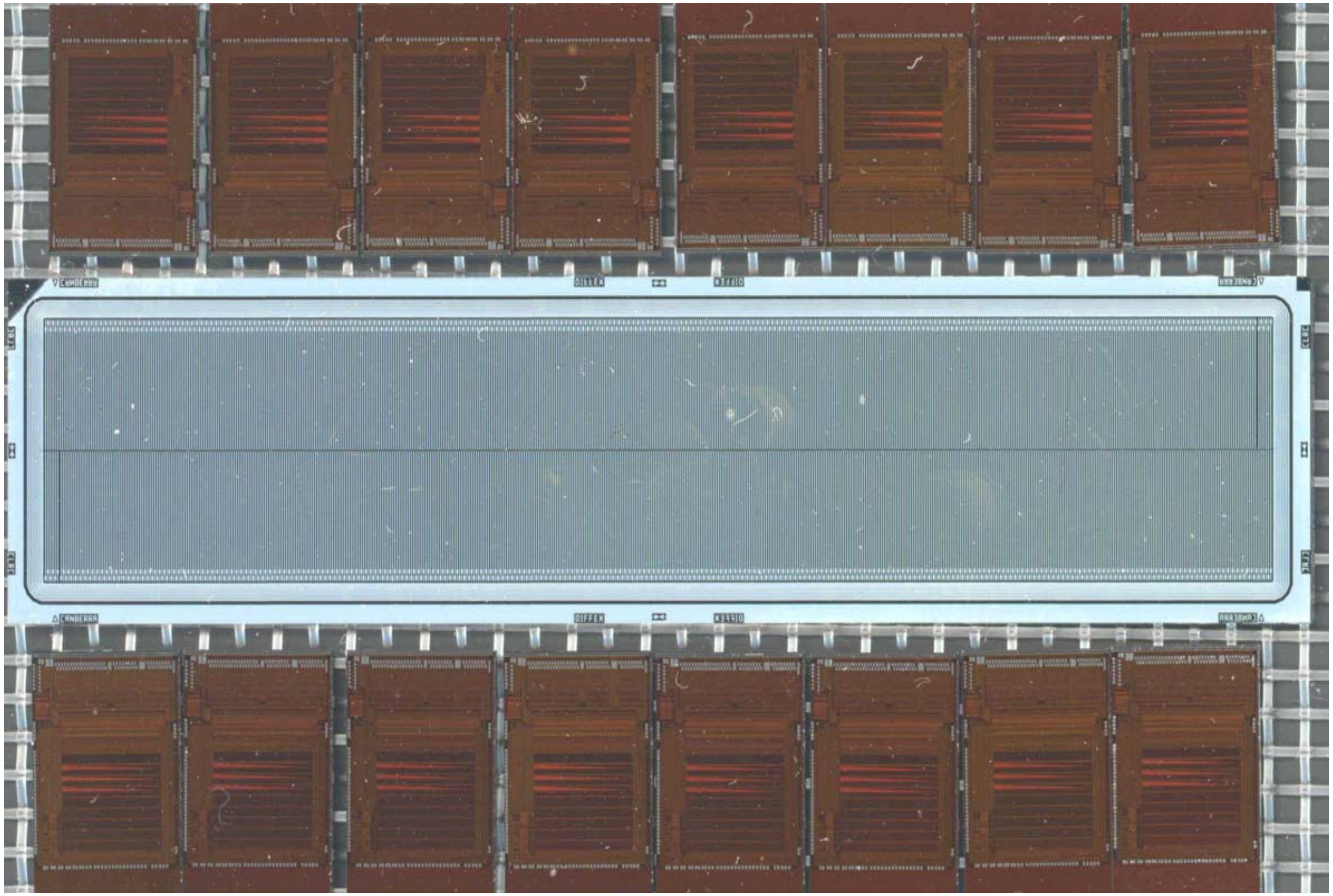
- 1024 channels @1MHz
- 16 level disc. per strip
- 16 bit counters per strip
- 64 channels per chip



SR Detector Development DIFFEX



SR Detector Development DIFFEX guard structures



Pixel Remarks

Guard Rings on planar Si introduce dead areas and are going to be difficult to remove.

Larger integration of the number of detector pixels will help. Increased size of detectors.

But where to next-

3 D silicon.

Pixel Remarks

3D Si (Sherwood Parker, Ed Westbrook..)

Looks like the technology is there so it is in the realm of near-term. HEP pushing this as well.

What about other materials..

Not just 3D but higher Z planar…

GaAs, CZT. Near term or longer term?

We need to ask the astronomy and space community.

And then that opens up Superconducting detectors plus UV and IR.

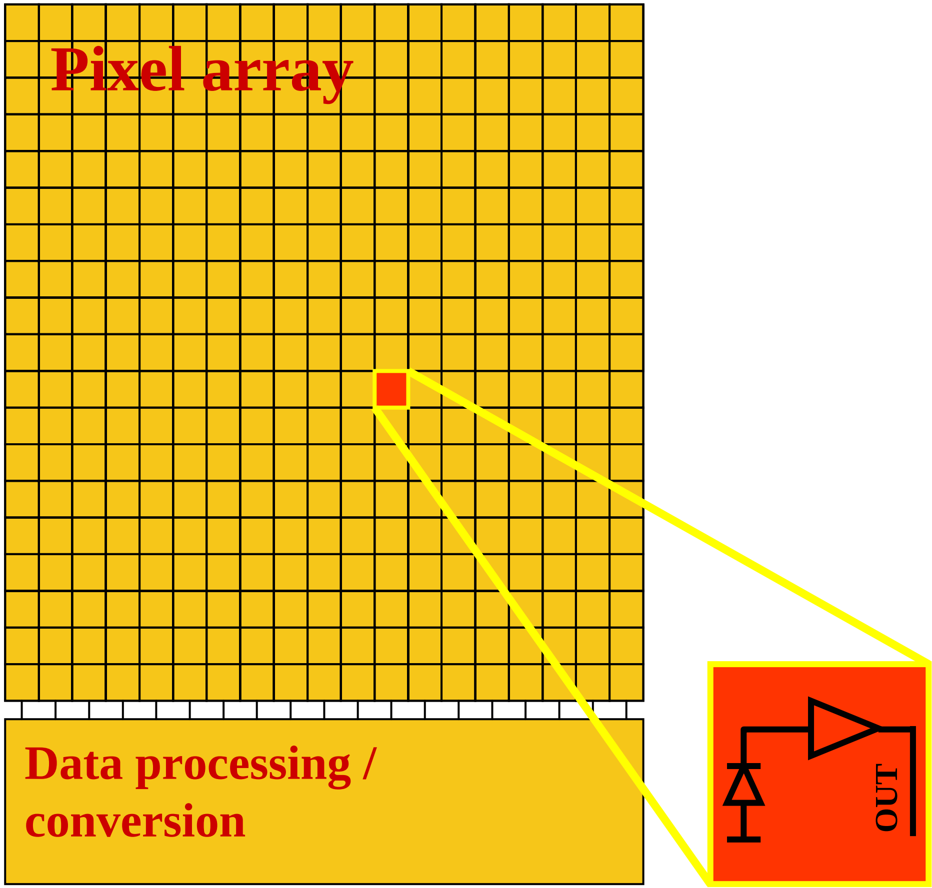
Monolithic Active Pixel Sensors (MAPS) are found in web cams, mobile phones, etc.

They are built in standard C-MOS processes and offer possibilities of large area detectors through stitching. (4cm by 4cm)

MAPS are pixels with active elements built in them. The active elements are user definable.

MAPS are now available in science grade.

Monolithic Active Pixels



Small pixels
Large pixel number (16M and above)
Fast
Read while taking data
Low noise
High Dynamic Range
Radiation hard
Intelligence
Routine CMOS manufacture

Applications in particle physics, space, SR, neutron scattering, laser physics, charged particle detection, confocal microscopy,..

Monolithic Active Pixels can be viewed as “CCDs with attitude”.

The possibilities with current technology are:-

very small pixels <2 microns

non linear response (logarithmic)

pixel behaves as a counter or an integrator depending on conditions.

Just read out what is there. (self triggering)

on pixel analogue memory. (streak camera mode)

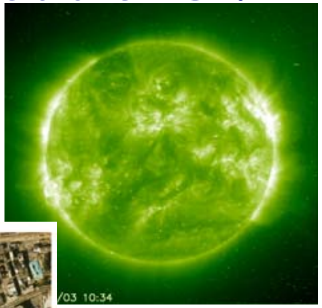
large format nk by nk where n >4

radiation hard

MAPS near-term

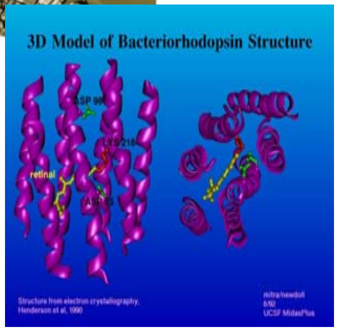
The 3 sensors are prototypes in a 0.25 um technology, optimised for image sensors for different applications :

Area sensor for ESA's Solar Orbiter for EUV imaging of Sun: 4K*3K sensor, 5 μm pixel, linearity over 14 bits



Linear sensor for Earth Observation 4K x 5 μm pixel, → 1 m ground resolution colour, on-chip 10-bit ADCs, ~ 1500 fps

Area sensor HEP and fast imaging (>1MHz):



Longer term- detector materials

X-ray and particle to light converters need work.

Phosphors and scintillators need better response times and better stability.

Otherwise you measure the response of the phosphor not the physical process you are trying to measure.

Better High Z detector material are needed otherwise all the photons produced are not counted.

We are not alone in needing work in this area.

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Concluding Remarks (1 of 2)

For future developments there are some key factors:-

- A clear understanding of the key science drivers.
- A clear understanding of the technologies available.
- Identifying the key players who own the technologies.
- Close collaboration between Scientists and Engineers.
- Close communication through meetings such as this and other ways.
- Maybe SR can take the lead instead of HEP (bump bonding!)

Concluding Remarks (2 of 2)

There are many opportunities for detectors on SR sources to improve existing SR science by closing the gap between photon provision and detection.

In the future SR needs to use photons efficiently (FBAD!).

We must also look at what other areas have to offer.

Funding must be sufficient to do this properly in a co-ordinated way.

Let’s learn from other areas of science where big international proposals are successful.

We are a global community- let’s use this to our advantage!